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Patent Application Transmittal Letter

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Sir:

Transmitted herewith for filing under 37 CFR 1.53(b) is a(n): ☒ Utility ☐ Design
☒ original patent application,
☐ continuing application,
☐ continuation-in-part
☐ continuation or ☐ divisional
of S/N none filed none

INVENTOR(S): Pau Soler

TITLE: "PRINTING A TRUE-INK REFERENCE, AND REFINING GRAY ACCURACY,
FOR OPTIMUM COLOR CALIBRATION IN INCREMENTAL PRINTING"

Enclosed are:

- ☒ The Declaration and Power of Attorney. ☐ signed ☒ unsigned or partially signed
☒ 8 sheets of ☐ formal drawings ☒ informal drawings (one set)
☒ Information Disclosure Statement and Form PTO-1449 ☐ Associate Power of Attorney
2 ACKNOWLEDGEMENT CARDS
☐ Priority document(s) ☒ (Other) FOR DATE STAMPING & RETURN (fee \$)

CLAIMS AS FILED BY OTHER THAN A SMALL ENTITY				
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By Peter Lippman
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Respectfully submitted,

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Date: Oct. 31, 2000

1 PRINTING A TRUE-INK REFERENCE, AND REFINING GRAY ACCURACY,
2 FOR OPTIMUM COLOR CALIBRATION IN INCREMENTAL PRINTING
3
4

5 RELATED PATENT DOCUMENTS
6

7 Closely related documents include coowned U. S. util-
8 ity patents and applications — all hereby incorporated by
9 reference in their entirety into this document. One is
10 U. S. 5,991,055 of Haselby et al., entitled "UNDERPULSED
11 SCANNER WITH VARIABLE SCAN SPEED, P. W. M. COLOR BALANCE,
12 SCAN MODES AND COLUMN REVERSAL" and of interest here for
13 its discussion of pulsed lamps of different colors, in
14 color sensing. Another such document is application se-
15 rial 08/960,766 of Bockman et al., entitled "CONSTRUCTING
16 DEVICE-STATE TABLES FOR INKJET PRINTING" and relevant for
17 its teaching of gray neutrality as a criterion for color
18 calibration at the gray axis and throughout the gamut —
19 and issued as U. S. Patent 6,____,____. A third related
20 document is application serial 09/183,819 of Baker, enti-
21 tled "COLOR-CALIBRATION SENSOR SYSTEM FOR INCREMENTAL
22 PRINTING", pertinent by virtue of its teaching of an aux-
23 iliary carriage and other variant components for use in
24 calibration — and issued as U. S. Patent 6,____,____.
25 Another somewhat related document is U. S. 5,657,137 of
26 Perumal, entitled "COLOR DIGITAL HALFTONING USING BLACK
27 AND SECONDARY COLOR REPLACEMENT", which takes up the proc-
28 esses of composite-black replacement and substitution.
29
30
31

1 FIELD OF THE INVENTION

2
3 This invention relates generally to devices and pro-
4 cedures for incremental printing of text or graphics on
5 printing media such as paper, transparency stock, or other
6 glossy media; and more particularly to a scanning thermal-
7 inkjet machine and method that construct text or images
8 from individual ink spots created on a printing medium, in
9 a pixel array. The invention is applicable to various
10 kinds of printing devices including facsimile machines and
11 copiers as well as printers.

12 Such "incremental" printing may be accomplished by
13 passing a single, full-page-width array (or one such array
14 for each of plural colorants) of marking elements continu-
15 ously along the length of a printing medium — or passing
16 the length of the medium under the array. Incremental
17 printing may instead be accomplished by passing a smaller
18 array (or again one for each of plural colorants) across
19 the width of the medium multiple times, in a process often
20 called "scanning" — the medium being advanced under the
21 scanning path or axis, between passes — to create a swath
22 or partial swath of marks in each pass.

23 In present-day commercial apparatus the grid is com-
24 monly a rectangular pattern of columns and rows, but for
25 purposes of this document need not be. For example a hex-
26 agonal pixel-grid pattern appears straightforwardly worka-
27 ble; and the invention would be applicable even in far
28 more remote grid forms, e. g. polar. The invention em-
29 ploys a colorant of a true black or secondary color as a
30 standard for correcting gray neutrality (absence of chro-
31 ma) or hue accuracy, respectively, of printing with three
32 or two superposed primary colorants.

1 BACKGROUND OF THE INVENTION

2
3 (a) Color calibration and correction — Color cali-
4 bration is a known function in color printers. Its objec-
5 tive is to provide consistency of color within an image,
6 and among all images printed by a given printer, and from
7 printer to printer.

8 Thus a proper color-calibration algorithm (CCA) com-
9 pensates for printer deviations in such a way that the
10 same nominal colorant values — i. e. quantities of cyan
11 (C), magenta (M), and yellow (Y) ink, and black (K) if
12 present — produce the same output from any printer which
13 undergoes the calibration. It is helpful to consider a
14 CCA as influencing 366, 368 (Fig. 15) a color-correction
15 stage 365, or the breakpoints 367 (i. e. the threshold
16 values) used in rendition, or both.

17 Conventional color correction, sometimes referred to
18 as a "transfer function", is a one-dimensional mapping
19 (Fig. 16) for each colorant 381-84 respectively. In
20 eight-bit data processing for incremental-printing sys-
21 tems, ordinarily the color-correction mapping is from
22 eight bits of nominal colorant (C, M, or Y, or K if pres-
23 ent) to eight bits of printer-specific colorant.

24 Various ways of forming a color-correction mapping
25 are known. In some products of the Hewlett Packard Compa-
26 ny, such mappings have been configured with the specific
27 aim of preserving the linearity of the colorants C, M and
28 Y — and again K if present.

29 Experiments have shown, however, that linearity of
30 colorants, while providing an adequate solution for cer-
31 tain kinds of color variations such as those caused by
32 drop-weight fluctuation, nevertheless has distinct limi-
33 tations. These limitations are particularly troublesome
34 for inkjet printing. First, when primary colorants ex-

hibit a hue shift — such as often caused, with certain media, by high humidity — the primary-linearity technique helps only very little.

Second, this technique fails to ensure a critical condition which is a hallmark of highest-quality printing systems: gray neutrality, or in other words absence of chroma, in nominally gray image features printed as combinations of the primary chromatic colorants C, M and Y.

(b) Composite or process black and gray — It is well known that combinations of these three subtractive chromatic primaries produce a close approximation to black, often called "process black". In the incremental-printing industry, composite/process black or gray when occurring outside highlight regions is usually replaced by actual black ink when available.

The object of such replacement is to reduce both ink usage and the volume of liquid deposited on the printing medium — and also to circumvent possible problems due to inaccuracy of the process-black approximation to actual black. Not all incremental-printing devices, however, have true-black ink cartridges. Therefore, in some such devices, composite black is the only way to achieve any black, and in such systems the accuracy of the process-black approximation assumes greater importance.

In incremental printing an important use of process black, or more precisely process gray, is for the benefit of its mechanical capability to spread or distribute, over a broader image area, colorant that appears neutral to the eye (see the Perumal document mentioned earlier). In this case the chromatic primaries are not overprinted but rather are adjacent — or even scattered rather widely — so that the overall impression of the visually integrated dots is of a smoother or silkier texture, though still one

1 of a very light gray. Therefore, in this rather sophisti-
2 cated case, process gray is important even if actual black
3 ink is available.
4

5 (c) Inaccuracy — When used with less finesse, how-
6 ever, process black — particularly in incremental print-
7 ing — tends more toward being merely inaccurate. Dis-
8 cerning observers detect some faint hue, some chromatic
9 component, in image areas that are nominally gray.

10 This chromatic component arises from imperfectly
11 balanced proportions of the three subtractive primary
12 colorants. The idea of "perfectly balanced proportions"
13 unfortunately is ephemeral, because ideal proportions
14 actually vary with the chemical and colorimetric charac-
15 teristics of the specific colorants employed.

16 Ideal proportions also vary with the electromechani-
17 cal characteristics of the printheads used to apply the
18 colorants to the printing medium. All these factors typ-
19 ically vary from batch to batch of colorants and heads.

20 Furthermore these characteristics interact in con-
21 founding ways with characteristics of the printing medium,
22 and of the sequence and even the timing of colorant depo-
23 sition — and these characteristics interact with each
24 other as well. The difficulty does not stop there, as
25 ambient conditions including temperature and humidity also
26 interact with the foregoing factors to prevent any stable,
27 single set of simple weight or volume proportions from
28 being usable over the life of a printing device.

29 The hue that appears in nominally gray regions, being
30 uncontrolled, is most typically irrelevant to the subject
31 matter of the particular image features. Esthetically,
32 therefore, it can often be quite jarring.
33

1 Here too, as in the foregoing process-black discus-
2 sion, the definition of "accuracy of proportions" is a
3 very elusive concept because optimum proportions really
4 depend upon a complex of attributes, including those of
5 the colorants, colorant-application devices, printing
6 medium, deposition sequence and timing, temperature and
7 humidity. Nevertheless, just as there is a clear defini-
8 tion of what is meant by "gray neutrality", it is possible
9 to fashion clear (if spectrally complicated) definitions
10 of what is meant by "red", "green" and "blue".

11 When these colors are not produced accurately, the
12 resulting esthetic impression can be even more troublesome
13 than slight chroma within regions that are nominally gray.
14 This is so for two reasons.

15 First, only limited sorts of objects in color photos
16 depend for their realism upon total absence of chroma.
17 Second, inaccuracies in the color secondaries manifest
18 themselves as hue shifts, to which observers typically re-
19 spond by saying that the colors are "off".

20 Results can be especially conspicuous in flesh tones
21 that have a strikingly unnatural cast, or in other objects
22 of well-known but inaccurately rendered hue that observers
23 may describe as "wrong". Earlier efforts to deal with the
24 problem of inaccurate secondaries have suffered either
25 from complete absence of secondary-accuracy feedback
26 information or — in systems that rely on field spectral
27 measurements using wideband sensing — at least from
28 absence of reliable hue references for those colors.

29
30 (f) Conclusion — Chroma appearing in nominally gray
31 regions, and secondary-color hue errors, have continued to
32 impede achievement of uniformly excellent inkjet printing.
33 Thus important aspects of the technology used in the field
34 of the invention remain amenable to useful refinement.

1
2
3 SUMMARY OF THE DISCLOSURE
4

5 The present invention introduces such refinement.
6 Before presenting a relatively formal introduction of the
7 invention, it may be helpful to mention some insights that
8 are considered part of the inventive process.

9 The process-black miscalibration problem discussed
10 above arises precisely from the previously mentioned in-
11 dependence of the prior-art mappings for the different
12 colorants. In such mapping regimes there is no place to
13 introduce crosscomparisons, and associated adjustments —
14 to remove the subtle intrusions of residual chroma which
15 can become so conspicuous in particular midtone features.

16 Similarly as to secondary colors that appear "off" or
17 "wrong", conventional mapping schemes rely on wideband
18 sensing. Such measurements can go awry because of various
19 different effects.

20 One class of errors arises from metamerism effects.
21 For instance, these types of measurement may implicitly
22 assume that the colorant has a particular spectral-reflec-
23 tance curve — which may in fact be very different from
24 that of the colorants being used. The sensor system in
25 the printing device integrates the reflected colors dif-
26 ferently than does the human visual mechanism.

27 It will be understood that the invention as practiced
28 and as defined in the appended claims does not rely for
29 its validity or utility upon correctness of these com-
30 ments. Now with these observations in mind, this discus-
31 sion will turn to a somewhat more-rigorous presentation.
32

33 In its preferred embodiments, the present invention
34 has several aspects or facets that can be used independ-

1 ently, although they are preferably employed together to
2 optimize their benefits.

3 In preferred embodiments of a first of its facets or
4 aspects, the invention is a method for color-calibrating a
5 printing device. The method includes the steps of using
6 the printing device to print a gray ramp with black ink,
7 and using the same printing device to print a nominally
8 gray ramp with composite-black ink.

9 In addition the method includes the step of measuring
10 and comparing the printed gray ramps. A further step is
11 employing the measured black-ink ramp as a standard to
12 correct the measured composite-black ramp.

13
14 The foregoing may represent a description or defini-
15 tion of the first aspect or facet of the invention in its
16 broadest or most general form. Even as couched in these
17 broad terms, however, it can be seen that this facet of
18 the invention importantly advances the art.

19 In particular, this method enables a printing system
20 to find the needed actually neutral combination not only
21 very precisely but also with relatively high assurance of
22 accuracy. This is because the system will closely match
23 the composite coloration to the actual black-ink values,
24 which are essentially unquestioned. The system carries
25 its neutral standard along with it, in actual physical
26 form.

27
28 Although the first major aspect of the invention thus
29 significantly advances the art, nevertheless to optimize
30 enjoyment of its benefits preferably the invention is
31 practiced in conjunction with certain additional features
32 or characteristics. In particular, preferably all the
33 steps are performed automatically.

1 pattern, in color space, that is substantially centered on
2 the nominal value.

3 Now reverting to the above-mentioned basic preference
4 of printing plural combinations of nonblack inks for a
5 particular gray tonal level, another subpreference is that
6 the employing (or the measuring and comparing) step
7 include searching the printed and measured plural combi-
8 nations of nonblack inks to find a combination that is
9 nearest a corresponding particular gray value.

10

11 Yet another basic preference is that the measuring
12 and comparing step (and/or the employing step) include
13 inserting measured values of the printed gray ramps into
14 equations representing a colorimetric model of the prin-
15 ter, and solving the equations to derive correction values
16 for use in adjusting ink signals in future printing. A
17 subpreference is that the colorimetric equations be solved
18 by iteration.

19 A particularly preferred form of these colorimetric
20 equations includes plural multiplicative expressions:

21

$$22 \quad H(t,n,a) = D(t,n) \cdot E(t,n) \cdot \dots \cdot F(t,n), \quad [1]$$

23

24 wherein H is a composite or hybrid color printed by use of
25 at least two constituent colors,

26 D is one of the constituent colors,

27 E is another of the constituent colors,

28 "... represents possible additional constituent
29 colors of the at least two,

30 F is a correction factor,

31 t is a tonal level at which H, D, E and "...
32 are evaluated,

33 n is a sensor channel at which all the above are
34 evaluated, and

1 programmed processor for performing this function may take
2 the form of portions of one or more processors that manage
3 the whole operation of the entire printer.

4
5 The foregoing may represent a description or defini-
6 tion of the second aspect or facet of the invention in its
7 broadest or most general form. Even as couched in these
8 broad terms, however, it can be seen that this facet of
9 the invention importantly advances the art.

10 In particular, this document earlier points out that,
11 on the one hand, colorimetric measurement of individual-
12 colorant ramps is known; and that on the other hand col-
13 orimetric measurement aiming to assay generally over an
14 entire color-space or gamut is known. A composite-black
15 ramp as such serves much better to probe and establish
16 actual gray neutrality than either of those diametrical
17 prior techniques.

18 Furthermore, specifically testing the nominally neu-
19 tral ramp for chroma — i. e. for neutrality as such —
20 not only far more effectively develops information for
21 achieving grays that are substantially free of chromatic
22 cast. In addition these grays in turn form a sturdy and
23 reliable central-axis chromatic backbone for accurate
24 color surrounding that axis.

25
26 Although the second major aspect of the invention
27 thus significantly advances the art, nevertheless to
28 optimize enjoyment of its benefits preferably the inven-
29 tion is practiced in conjunction with certain additional
30 features or characteristics. In particular, preferably
31 the measuring means include means for measuring the prin-
32 ted ramp in at least three different spectral bands.
33 While something can be accomplished using two, and it is

1 the step of using the printer to print a ramp in a partic-
2 ular color with actual ink of that color.

3 In addition the method includes using the same prin-
4 ter to print a ramp nominally in the particular color but
5 with inks of other colors; and then measuring and compar-
6 ing the printed ramps. Yet another step is using the
7 measured actual-ink ramp as a standard to calibrate and
8 correct the measured other-colors-ink ramp — and also to
9 correct other printing with those other colors.

10
11 The foregoing may represent a description or defini-
12 tion of the third aspect or facet of the invention in its
13 broadest or most general form. Even as couched in these
14 broad terms, however, it can be seen that this facet of
15 the invention importantly advances the art.

16 In particular, this aspect of the invention more
17 broadly provides benefits analogous to those discussed
18 above for the first aspect. These benefits are provided
19 now with respect to precision, accuracy and reliability of
20 composite secondaries, as well as composite black.

21
22 Although the third major aspect of the invention thus
23 significantly advances the art, nevertheless to optimize
24 enjoyment of its benefits preferably the invention is
25 practiced in conjunction with certain additional features
26 or characteristics. In particular, preferably the actual
27 ink is red ink, green ink, or blue ink — and the inks of
28 other colors are magenta ink and yellow ink in combina-
29 tion, or yellow ink and cyan ink in combination, or cyan
30 ink and magenta ink in combination.

31
32 In preferred embodiments of its fourth major indepen-
33 dent facet or aspect, the invention is a method for auto-
34 matically color-calibrating a printer. The method compri-

1 ses the steps of modeling an actual color-reproduction
2 system of the printer in a color space that is transformed
3 by contraction.

4 The contraction brings the machine-primary color axes
5 closer to neutral gray. Another step of the method is
6 performing a color calibration in the contracted model of
7 the printer color-reproduction system.

8 Still another step of the method is applying a re-
9 verse transform to reexpand the calibration results. That
10 is, the calibration is expressed in terms of the actual
11 color-reproduction system of the printer.

12
13 The foregoing may represent a description or defin-
14 ition of the fourth aspect or facet of the invention in
15 its broadest or most general form. Even as couched in
16 these broad terms, however, it can be seen that this facet
17 of the invention importantly advances the art.

18 In particular, by operating in a contracted machine
19 space this facet of the invention enables the calibration
20 procedure to operate much more finely. This method there-
21 by yields a more precise and generally more accurate over-
22 all result.

23 Although the fourth major aspect of the invention
24 thus significantly advances the art, nevertheless to
25 optimize enjoyment of its benefits preferably the inven-
26 tion is practiced in conjunction with certain additional
27 features or characteristics. In particular, preferably
28 this facet of the invention is practiced in conjunction
29 with the first three, introduced above.

30
31
32
33 All of the foregoing operational principles and
34 advantages of the present invention will be more fully

1 appreciated upon consideration of the following detailed
2 description, with reference to the appended drawings, of
3 which:

4
5
6
7 BRIEF DESCRIPTION OF THE DRAWINGS

8
9 Fig. 1 is a partly diagrammatic showing of color pat-
10 ches for calibrating a single tonal level in a composite-
11 black neutral ramp, by comparison with a true-black ramp;

12 Fig. 2 is a graph of representative sensor responses
13 in three channels, for both composite and true black, at a
14 common nominal tonal level — for preliminary determina-
15 tion of needed rescaling;

16 Fig. 3 is a conceptual graph showing representative
17 spectral sensitivities in the three sensor channels;

18 Fig. 4 is a test pattern with primary ramps (in the
19 top row) of cyan, magenta, yellow and black — followed by
20 composite ramps, in the bottom row, of red (yellow plus
21 magenta), green (cyan plus yellow), blue (magenta plus
22 cyan) and black (all three primaries);

23 Fig. 5 is a conceptual graph showing how the three
24 primary colorants influence (ideally) the three sensor
25 channels;

26 Fig. 6 is a like graph but showing how the behavior
27 of each primary in a nominally black composite printout is
28 adjusted, according to the invention, to make the compos-
29 ite actually match true black;

30 Fig. 7 is a graph of reflectivity as a function of
31 wavelength for each primary and the bare printing medium;

32 Fig. 8 is a numerical example, in the form of a tabu-
33 lation, showing how the Fig. 2 rescaling is completed;

1 Fig. 9 is a graph of the above-introduced contraction
2 principle of the invention, diagramed in CMY space, with
3 the solid and dashed colored lines C, M, Y, C', M' and Y'
4 being the original and modified axes respectively — thus
5 showing how the axes are shrunk, in terms of the angle of
6 deviation;

7 Fig. 10 is a perspective drawing of the invention as
8 incorporated into a representative printing device that is
9 a large-format printer/plotter;

10 Fig. 11 is a like drawing of the scanning subsystem
11 which carries printheads and a sensor across the printing
12 medium in the Fig. 10 device;

13 Fig. 12 is a block-diagrammatic representation of a
14 hardware system, incorporating the Fig. 10 and 11 prin-
15 ter/plotter, according to the invention;

16 Fig. 13 is a partial view with an alternative sensor;

17 Fig. 14 is a flow chart for a method according to the
18 invention;

19 Fig. 15 is a high-level flow chart indicating the re-
20 lationship between a color-calibration algorithm (CCA), a
21 color-correction stage and a rendition stage; and

22 Fig. 16 is an exemplary color-correction mapping.

23
24
25
26 DETAILED DESCRIPTION
27 OF THE PREFERRED EMBODIMENTS

28
29 1. GRAY NEUTRALITY AS A COLOR-CORRECTION STANDARD

30
31 Experiments have shown that building the transfer
32 functions in such a way as to establish gray neutrality
33 foremost, instead of individual-primary linearity, yields
34 better results. In particular, remarkably, the previously

mentioned extreme sensitivity of colors to humidity is greatly reduced.

Furthermore, as mentioned earlier, gray neutrality is itself a desired property of the printer. With this technique this property is ensured.

The gray-neutrality approach, like some prior methods, is reliant upon comparative measurements of just-printed test patterns — using a sensor 251 (Figs. 11 through 13). As a matter of convenience, in printing devices of the scanning type the sensor is most typically mounted on the carriage 220 which holds the printheads.

This arrangement enables positioning of the sensor automatically over any part of the test pattern (Fig. 1 or 4) on the printing medium 4A (Figs. 12, 13). It is a particularly advantageous arrangement in that many printing devices already carry a so-called "line sensor" on the carriage, for use in alignment, edge tracking and so on.

Thus use of the already-available line sensor makes double duty of that component, achieving additional functionality at substantially no cost. The line sensor, however, is not necessarily an ideal choice: it is designed for simple geometrical measurements and not optimized for colorimetry.

The previously mentioned Baker document teaches alternatives such as use of an auxiliary carriage with a sensor of finer quality. Depending on the importance of colorimetric accuracy in a particular printing device, the line sensor may be entirely adequate.

In operation, a true-black ramp e. g. 174 (also seen as individual patches 101) is measured and compared with approximations using composite black 179 (also 111, 121-25, 131-35). The composite-black approximation is then very delicately refined to approach the true-black ramp very precisely.

1 This refinement, maintained (in effect, propagated)
2 throughout the gamut of the printing device, constitutes
3 the desired calibration for use in all subsequent printing
4 until the next calibration. Two alternative ways of cali-
5 brating, both based on this principle, are described in
6 the two subsections that follow.

7 For purposes of this document, preferably a three-
8 lamp (typically three-LED) sensor 251, 251' (Fig. 12) is
9 in use, but as detailed below a single broadband lamp
10 251'BB (Fig. 13) may be substituted as preferred. Before
11 the calibration procedure itself is started, the true-
12 black ramp should be linearized using conventional linea-
13 rization techniques or better.

14 15 16 2. COMPLETE SAMPLING

17
18 (a) General procedure — This may be regarded as the
19 most straightforward method for performing the gray-neu-
20 trality calibration:

- 21
22 ■ A black patch 101 (Fig. 1) is printed and measured,
23 for a particular tonal level (in the illustrated
24 example, fifty percent).
- 25
26 ■ A sampling 111, 121-125, 131-135 of the composite
27 black nominally near the same level, including small
28 variations 121-125, 131-135 in all colorant dimen-
29 sions (C, M, Y), is printed and measured.
- 30
31 ■ The most similar composite-black patch e. g. 123 is
32 chosen as the corrected value.

The number of patches to be printed is at least $3^3 = 27$, corresponding to at least three colorants (C, M, Y) and at least three states (+, =, - or in words "high", "nominal" and "low").

The sampling can be grosser or finer, and some simple interpolation (e. g. linear or cubic) can be performed to improve the accuracy. Thus more than three states may be sampled (for instance ++, +, =, - and --).

The printing system may have more than three chromatic colorants, as for example including dilute magenta and dilute cyan. If so, it is advisable to include the additional colorants in the calibration procedure.

The same procedure is repeated for as many points as desired (usually between eight and sixteen), along the gray gamut from black nearly to white. In this way the full gray-scale range is adjusted. Next the transfer functions are calculated based on these correction values.

(b) Range — The black and composite-black ranges may not be, and usually are not, the same. Most commonly the true-black gamut extends further toward the dark end of the gray axis than does composite black.

To resolve this range misfit, the system does not attempt to match equal densities, e. g. fifty percent composite black with fifty percent true black. Instead a rescaling is performed — to match one hundred percent of composite black against e. g. eighty percent of true black.

(c) Centerpoint, sampling shape and sequencing — It is very likely that the correct combination of C, M and Y that yields gray is quite far from equal amounts of those primaries. Therefore it may be very inefficient to performing sampling that is centered on equal amounts.

1 To improve efficiency, and in some cases accuracy as
2 well, the tendency of the prior points (for instance, they
3 may all be ten percent and higher for one primary) may be
4 extrapolated. For example, if there is always a need for
5 slightly more magenta, the sampling may be centered at +5%
6 magenta at the outset.

7 Further, the sampling in CMY space need not be cubi-
8 cal, i. e. \pm for each of the three inks. It can also
9 be a sphere, a pyramid, or any other geometrical arrange-
10 ment that provides a reasonable sampling of the colorant
11 space around or near the nominal combination of values.

12 If desired the search for best neutral match can be
13 further refined by iteration, with different increments of
14 sampling. At each pass, the solutions are used as new
15 centerpoints.

16 In other words, a first pass may be performed with
17 $\pm 10\%$ variation about zero (or about e. g. +5% magenta as
18 suggested above), yielding a best solution. A new pass is
19 then performed with $\pm 5\%$ variation about that best solution
20 from the first pass, yielding a new best solution — and
21 so on for some specified number of iterations or until the
22 solution converges to some specified precision.

23
24 (d) Advantages: robustness, minimum storage — In
25 addition to the benefits of the gray-neutrality on its
26 own, the algorithms discussed here are particularly resis-
27 tant to LED variations. This is due to the fact that the
28 interpretation of all measurements is relative rather than
29 absolute.

30 Because all the corrections are based upon relative
31 rather than absolute quantities, practice of the invention
32 requires no LED characterization table or the like. The
33 only constraint is that the illumination be approximately
34 a partition of the visible spectrum.

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3. MODELING

Modeling is in essence a tactic for reducing the number of patches to be measured, by invoking some accurate process of estimation. This tactic reduces the time required for printing and measuring, along with the quantities of printing medium and colorant required.

Many models are possible. The general technique of modeling for other predictive or corrective purposes, however, is known; hence people skilled in this field will find the simple examples discussed here adequate to guide practice of the present invention.

(a) Measurement — If a three-LED sensor (e. g. line sensor) — or broadband illumination with three-band spectral differentiation — is used, the sensing system can be regarded as a three-broadband spectral detector with three main channels: red 146 (Fig. 3), green 147 and blue 148. In preferred embodiment of the invention, this detector measures reflected light from a test pattern made up of pure-colorant ramps 171-174 (Fig. 4) and composite ramps 176-179.

The pure-colorant part of the pattern includes one ramp each for cyan 171, magenta 172, yellow 173 and black 174. The composite part includes one ramp each for red (a magenta-plus-yellow composite) 176, green (cyan plus yellow) 177, blue (cyan plus magenta) 178 and black (cyan plus magenta plus yellow) 179.

With each sensor channel in turn — i. e., with each LED — the system measures the chromatic primaries (CMY), the secondaries ($R=M+Y$, $G=Y+C$, $B=C+M$), the composite-black ($cK=C+M+Y$) and the black (K) ramps. It is a matter of operational convenience and design choice whether the entire

1 pattern is measured with each sensor channel before moving
2 on to the next sensor channel, or instead the measurements
3 in all three channels are performed in each part of the
4 pattern before proceeding to the next part of the pattern.

5 The latter approach, however, is generally preferable
6 as a practical matter, since flashing LEDs through a cycle
7 (see Haselby) can be accomplished very quickly — requir-
8 ing no mechanical movement of the printhead carriage or
9 printing-medium advance drive. If desired, such measure-
10 ments can be made while the mechanical systems are in mo-
11 tion (incurring an accuracy penalty due to measuring dif-
12 ferent portions of each patch, in the different spectral
13 bands). Hence cycling through the LEDs, at each patch, in
14 principle can provide an entire measurement-data array
15 with just one slow pass over each row of the test pattern.

16
17 (b) Meaning of the data — In each printer the re-
18 sults of the ramp measurements will be a family of numeri-
19 cal tabulations, i. e. data arrays —

$$C = C(\underline{t}, \underline{n})$$

$$M = M(\underline{t}, \underline{n}) \quad [3]$$

$$Y = Y(\underline{t}, \underline{n})$$

24
25 in which t is the nominal tonal value, along the ramp, for
26 which each measurement is made (often expressed as a col-
27 orant percentage or fraction), and n the sensor channel
28 (r, g, b) used to make the measurement.

29 At the outset, these data represent simply the numer-
30 ical value of reflectance uniquely corresponding to each
31 specified combination of ramp position and channel. That
32 is to say, at this stage the t and n values are the inde-
33 pendent variables, and the C, M, Y values, the dependent.

It is helpful, however, to look ahead to the end of the process and keep in mind that the values of \underline{t} — when later divorced from channel indices $\underline{n} = \underline{r}, \underline{g}, \underline{b}$ and also when referred to the primary colorants CMY of the printing system rather than the sensor channels $\underline{r}, \underline{g}, \underline{b}$ — will become the dependent variables that will be sought as the end result of the calibration process. In particular these numbers \underline{t} are the tonal values which the printing stage must be instructed to produce, to obtain particular tonal values of gray:

$$\begin{aligned}\underline{t}_C &= \underline{t}(\underline{t}_K) \\ \underline{t}_M &= \underline{t}(\underline{t}_K) \\ \underline{t}_Y &= \underline{t}(\underline{t}_K).\end{aligned}\quad [4]$$

In general this correspondence will not be an equality. In other words when a particular tonal value \underline{t}_K of gray is desired, the printing device must in general be directed to produce some other tonal values $\underline{t}_C, \underline{t}_M, \underline{t}_Y$ of C, M and Y respectively —

$$\begin{aligned}\underline{t}_C &\neq \underline{t}_K \\ \underline{t}_M &\neq \underline{t}_K \\ \underline{t}_Y &\neq \underline{t}_K\end{aligned}\quad [5]$$

and this inequality in fact is why calibration is needed.

Now with the perspective in mind that the tonal-value numbers \underline{t} will be the variables sought, it can be correspondingly appreciated that the photometric-measurement numbers C, M, Y —

$$\begin{aligned}C &= C(\underline{t}, \underline{n}) \\ M &= M(\underline{t}, \underline{n}) \\ Y &= Y(\underline{t}, \underline{n})\end{aligned}\quad [6]$$

1 will later be the data to be read from the tabulations, in
2 the final steps of solving for t_c , t_m , t_y . The usefulness
3 of the initial data tabulation resides in the fact that
4 the uniqueness of the tabulation works in both directions.

5 Thus the measured C, M, Y values can be simply read
6 out from the tabulation in response to desired values of
7 t_c , t_m , t_y . Moreover, intermediate values of the nominal
8 C, M, Y data are available through interpolation. Accord-
9 ingly each needed value of C, M or Y for a particular col-
10 or will be inferred directly, through the tabulation, by a
11 corresponding specified value of t .

12
13 (c) Nonideal behavior of colorants — Interpretation
14 of the sensor data proceeds by construing the common re-
15 sponse 151 (Fig. 5) in the red and green channels r , g as
16 representing cyan. Similarly, the common response 152,
17 153 in the red and blue channels r , b is construed as rep-
18 resenting magenta, and the common sensor response 154 in
19 the green and blue channels g , b as representing yellow.
20 Imperfections in these assumptions are discussed below.

21 The invention seeks to determine which amount of each
22 colorant is needed to achieve a neutral composite black
23 (cK). If inks actually behaved ideally in the sense that
24 coloring effects were confined to respective nonoverlap-
25 ping sensor channels — as described in the preceding
26 paragraph — then measuring only the primaries (CMY) and
27 black (K) would suffice.

28 In that case, the response 156, 157, 158 (Fig. 6) of
29 each primary (CMY) would simply be adjusted to produce the
30 same response 141 as the black colorant. Unfortunately
31 inks do not behave in that way — as seen from the fact
32 that the primary response curves 161-164 (Fig. 7) are not
33 rectangular functions at all but rather continuous curves

1 with quite different behavior in different spectral regions.

2 For instance the cyan reflectivity 161 is not equal
3 in the blue and green as suggested 151 in Fig. 5, but in-
4 stead peaks in the blue and falls with increasing wave-
5 length through the green. It even displays minor return
6 161' in the far red.

7 Analogously the magenta reflectivity 162, 163 is not
8 equal in the blue and red as suggested 152, 153 in Fig. 5.
9 Instead it has by far its major return 162 in the red and
10 only a relatively quite small subsidiary return 162 in the
11 blue.

12 Still further, yellow reflectivity 164 is not equal
13 in the green and red as suggested 154 in Fig. 5, but in-
14 stead falls off in the lower end of the green band. It
15 returns quite significantly into the blue, where in ideal
16 terms it should be substantially nonreflective.

17 Not even the reflectivity 166 of the printing medium
18 is wholly as might be classically expected, since its
19 reflectivity falls abruptly in the lower end of the blue.
20 To complicate matters still further the reflectivity of
21 pure, true black ink is anomalously very substantial in
22 the far red — exceeding, for instance, that of the magen-
23 ta peak 162 in the blue.

24
25 (d) Model equations — To compensate these cross-
26 channel and other nonideal effects, we build a model to
27 describe actual ink behavior. At the outset a general
28 multiplicative expression may be noted, for use in rela-
29 tion to both secondary colorants and black (repeating
30 equation [1]):

31
32
$$H(\underline{t}, \underline{n}, \underline{a}) = D(\underline{t}, \underline{n}) \cdot E(\underline{t}, \underline{n}) \cdot \dots \cdot F(\underline{t}, \underline{n}). \quad [1']$$

33

Here H is a hybrid or composite color printed by use of at least two constituent colors,

D is one of the constituent colors,

E is another of the constituent colors,

". . ." represents possible further constituent colors of the "at least two",

F is a correction factor,

\underline{t} is a tonal level at which H, D, E and ". . ." are evaluated,

\underline{n} is a sensor channel at which all the above are evaluated, and

\underline{a} is a scaling factor that relates overall range of the hybrid color with overall range of the constituent colors.

In some of the expressions, $H = cK$, $D = S_1$ and $E = S_2$, where cK is composite black and S_1 and S_2 are secondaries. In others of the expressions, $H = S$, $D = P_1$ and $E = P_2$, where S is a secondary and P_1 and P_2 are primaries; in these latter expressions, $\underline{a} = 1$.

Now to demonstrate application of this general expression to the several cases involved in accordance with the invention, consider first forming the secondaries — with the correction factor $F(n) = \alpha_N$:

$$\begin{aligned} R(\underline{t}, \underline{r}) &= M(\underline{t}, \underline{r}) \cdot Y(\underline{t}, \underline{r}) \cdot \alpha_R(\underline{t}) \\ G(\underline{t}, \underline{g}) &= C(\underline{t}, \underline{g}) \cdot Y(\underline{t}, \underline{g}) \cdot \alpha_G(\underline{t}) \\ B(\underline{t}, \underline{b}) &= C(\underline{t}, \underline{b}) \cdot M(\underline{t}, \underline{b}) \cdot \alpha_B(\underline{t}), \end{aligned} \quad [7]$$

where

R, G and B are the colors being formed as ink combinations,

other secondaries. In order to simplify the model, nonetheless, each correction factor α is computed unidimensionally, and its index is the average of the tonal values of its two constituents:

$$\alpha(t_M, t_Y) = \alpha\left(\frac{t_M + t_Y}{2}\right) . \quad [8]$$

A more complex model would yield better results but would require more samples. To simplify the notation, in most of the remainder of this discussion when referring to the correction factors α no sensor channel will be specified for the tonal values. That is, for example correction factors $\alpha_G(0.7)$, $\alpha_R(0.3)$ and $\alpha_B(0.9)$ will all be written simply $\alpha(0.7)$, $\alpha(0.3)$ and $\alpha(0.9)$ respectively.

The foregoing discussion explores application of a general expression for a composite color H to composite secondary colors. Next consider application of the same general expression to composite grays:

$$\begin{aligned} cK(\underline{t}, \underline{r}) &= C(\underline{t}, \underline{r}) \cdot R(\underline{t}, \underline{r}) \cdot \beta_R(\underline{t}) \\ cK(\underline{t}, \underline{g}) &= M(\underline{t}, \underline{g}) \cdot G(\underline{t}, \underline{g}) \cdot \beta_G(\underline{t}) \\ cK(\underline{t}, \underline{b}) &= Y(\underline{t}, \underline{b}) \cdot B(\underline{t}, \underline{b}) \cdot \beta_B(\underline{t}) , \end{aligned} \quad [9]$$

where

cK is composite black, formed as a three-colorant combination of cyan, magenta and yellow (CMY),
C, M and Y are those constituent primary colors,
R, G and B are red, green and blue as two-colorant combinations of those primaries,
 β is a correction factor in each channel respectively,

t is a tonal level (equivalently, an ink percentage) at which C, M, Y and β are evaluated, and r, g and b are the sensor channels at which all the above are evaluated.

Analogously to the preliminary step in the primary-colorant case discussed earlier, the foregoing three expressions are rearranged to solve for the three correction factors β :

$$\begin{aligned}\beta_R(t) &= \frac{cK(t, r)}{C(t, r) \cdot R(t, r)} \\ \beta_G(t) &= \frac{cK(t, g)}{M(t, g) \cdot G(t, g)} \\ \beta_B(t) &= \frac{cK(t, b)}{Y(t, b) \cdot B(t, b)}\end{aligned}\quad [10]$$

Here as with the α derivations discussed earlier, actual numerical values can now be obtained for β , to be inserted into final expressions for t. Here, to avoid circular definition in each channel, the same tone-definition issue discussed above for α calculations recurs; for example:

$$\beta_G(t_M, t_G) = \beta_G\left(\frac{t_M + t_G}{2}\right) = \beta_G\left(\frac{t_M + \frac{t_C + t_Y}{2}}{2}\right). \quad [11]$$

(e) Condition — Solution of the system of equations requires one further constraint. The constraint to be imposed is simply that composite black cK matches true black K at all bands, or more precisely all bands that can be measured — in other words, in all the sensor channels.

In the notation introduced above, this condition appears thus:

$$\begin{aligned}
1 \quad & cK(\underline{t}, \underline{r}) = K(\underline{a}, \underline{t}, \underline{r}) \\
2 \quad & cK(\underline{t}, \underline{g}) = K(\underline{a}, \underline{t}, \underline{g}) \quad [12] \\
3 \quad & cK(\underline{t}, \underline{b}) = K(\underline{a}, \underline{t}, \underline{b})
\end{aligned}$$

4
5 for all \underline{t} — but usually represented only as a sampling of
6 e. g. roughly seventeen of the tonal values \underline{t} . This ex-
7 pression includes the previously defined scaling factor \underline{a}
8 that interrelates the overall ranges of the composite col-
9 or (here cK) and its constituent colors (here K).

10
11 (f) Ranging adjustment — The scaling factor \underline{a} is
12 necessary because of the range problem mentioned in sub-
13 section 2, "COMPLETE SAMPLING", above. Other, more com-
14 plex functions could be used, but a simple factor is
15 sufficient.

16 A single, unitary value of \underline{a} for use throughout the
17 system is found empirically. This is done by comparing
18 the darkest available data row in the composite-black (cK)
19 measurement tabulation 166 (Fig. 8) — namely, one-hundred
20 percent of all three primaries — with the full true-black
21 (K) measurement tabulation 168.

22 As demonstrated by the numerical example in the il-
23 lustration, higher percentages (\underline{t}) of true-black (K) ink
24 correspond to lower reflectance values C, M, Y . At the
25 bottom of the true-black tabulation 168, these reflectance
26 values approach zero.

27 The darkest available row in the composite-black (cK)
28 tabulation 166 typically is less dark (i. e. has a higher
29 reflectance value) than the true-black (K) tabulation 168,
30 in at least one column (C, M or Y). In the example, that
31 less-dark entry 167 is the magenta value "0.3712", which
32 is much higher than the true-black one-hundred-percent
33 entry "0.213"; and in fact also higher than the ninety-
34 percent magenta entry "0.2917".

From these observations it will now be clear that it would be fallacious to attempt to match one-hundred percent of composite black with one-hundred percent of true black. The maximum composite-black reflectance is even just slightly higher than the eighty-percent magenta value 169, which appears as "0.3704".

This eighty-percent true-black entry 169, however, is a rather close match to the hundred-percent composite-black entry 167. Thus for purposes of the example the desired scaling factor may be set to $\underline{a} = 0.8$ (i. e. eighty percent).

Those skilled in the field will appreciate that a more precise value of \underline{a} if desired can be obtained either by iterated printing and measurement of a test pattern with finer resolution, or by interpolation. In any event, given the determined value of the scaling factor \underline{a} , the next step is to complete the calibration.

(g) Solution — Linking the above-stated "condition" with the composite-black model yields:

$$\begin{aligned} cK(\underline{t}, \underline{r}) &= K(\underline{a}, \underline{t}, \underline{r}) = C(\underline{t}, \underline{r}) \cdot R(\underline{t}, \underline{r}) \cdot \beta_R(\underline{t}) \\ cK(\underline{t}, \underline{g}) &= K(\underline{a}, \underline{t}, \underline{g}) = M(\underline{t}, \underline{g}) \cdot G(\underline{t}, \underline{g}) \cdot \beta_G(\underline{t}) \quad [13] \\ cK(\underline{t}, \underline{b}) &= K(\underline{a}, \underline{t}, \underline{b}) = Y(\underline{t}, \underline{b}) \cdot B(\underline{t}, \underline{b}) \cdot \beta_B(\underline{t}). \end{aligned}$$

Discarding the left-hand member of this three-way equality and substituting the previously determined modeling expressions for the secondaries R, G, B —

$$\begin{aligned} K(\underline{a}, \underline{t}, \underline{r}) &= C(\underline{t}, \underline{r}) \cdot M(\underline{t}, \underline{r}) \cdot Y(\underline{t}, \underline{r}) \cdot \alpha_R(\underline{t}) \cdot \beta_R(\underline{t}) \\ K(\underline{a}, \underline{t}, \underline{g}) &= M(\underline{t}, \underline{g}) \cdot C(\underline{t}, \underline{g}) \cdot Y(\underline{t}, \underline{g}) \cdot \alpha_G(\underline{t}) \cdot \beta_G(\underline{t}) \quad [14] \\ K(\underline{a}, \underline{t}, \underline{b}) &= Y(\underline{t}, \underline{b}) \cdot C(\underline{t}, \underline{b}) \cdot M(\underline{t}, \underline{b}) \cdot \alpha_B(\underline{t}) \cdot \beta_B(\underline{t}). \end{aligned}$$

Dividing through each of these remaining equations to isolate C, M, Y produces these expressions for each primary as a function of desired tonal level — and the other primaries:

$$\begin{aligned} C(t, r) &= \frac{K(a, t, r)}{M(t, r) \cdot Y(t, r) \cdot \alpha_R(t) \cdot \beta_R(t)} \\ M(t, g) &= \frac{K(a, t, g)}{M(t, g) \cdot Y(t, g) \cdot \alpha_G(t) \cdot \beta_G(t)} \\ Y(t, b) &= \frac{K(a, t, b)}{M(t, b) \cdot Y(t, b) \cdot \alpha_B(t) \cdot \beta_B(t)} \end{aligned} \quad [15]$$

This is the three-equation/three-variable system to be solved.

As mentioned earlier, ultimately the variables to be found are the numerical values of \underline{t}_N (where $N = R, G$ or B) which the printing device must invoke to obtain desired composite-black neutrality at some corresponding nominal tonal value \underline{t}_K of desired black.

These numerical values of \underline{t}_N , however, are best reached by finding their associated C, M and Y through solution of the equations just above. Then, as also mentioned earlier, the needed \underline{t}_N are simply inferred (read) from the tabulation — with interpolation as appropriate.

In much of this discussion, various subindices have been omitted to simplify the presentation. It is now helpful, however, to display the above three expressions with all the subindices more explicitly specified as follows.

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$$\begin{aligned}
C(t_c, r) &= \frac{K(a, t, r)}{M(t_M, r) \cdot Y(t_Y, r) \cdot \alpha_R \left(\frac{t_M + t_Y}{2} \right) \cdot \beta_R \left(\frac{t_c + \left(\frac{t_M + t_Y}{2} \right)}{2} \right)} \\
M(t_M, g) &= \frac{K(a, t, g)}{C(t_c, g) \cdot Y(t_Y, g) \cdot \alpha_G \left(\frac{t_c + t_Y}{2} \right) \cdot \beta_G \left(\frac{t_M + \left(\frac{t_c + t_Y}{2} \right)}{2} \right)} \\
Y(t_Y, b) &= \frac{K(a, t, b)}{M(t, b) \cdot Y(t, b) \cdot \alpha_B \left(\frac{t_c + t_M}{2} \right) \cdot \beta_B \left(\frac{t_Y + \left(\frac{t_c + t_M}{2} \right)}{2} \right)}
\end{aligned}$$

[16]

where: α , β are the model correction factors found or estimated from the measured values, as exhibited earlier,

t_c , t_M , t_Y are the tonal values (color percentages) of cyan, magenta and yellow — i. e., the ultimately needed variables,

a is the rescaling factor,

t is the tonal value of the grayscale for which t_c , t_M , t_Y are sought,

K are true-black as measured from the test pattern, and

C , M , Y are chromatic primaries, also as measured.

A way to complete the solution is iteratively — for instance, first find the $C(t, r)$, given the initially measured M and Y . With this first-found value of $C(t, r)$, the next step is to find (directly from the line-sensor data

1 as described above) the tonal value \underline{t}_C of cyan that is
2 needed to provide a neutral gray.

3 Next the procedure goes to the next equation, the
4 equation for M, again using the initially measured Y but
5 now with the newly estimated C — and then to the third
6 equation, the equation for Y, now inserting both the new C
7 and M. This round is then iterated until values converge
8 to the desired accuracy.

9 The order of the equations can be changed to reach
10 convergence more quickly. In general the best sequence is
11 Y, then C and then M — but in practice the preferred or-
12 der depends on the particular ink set in use.

13
14 (h) Process summary — The foregoing discussion
15 shows that the invention is practiced by these steps:

- 16 1. print ramps (C, M, Y, R, G, B, cK, K),
- 17 2. measure ramps with each LED of sensor,
- 18 3. find scaling factor \underline{a} from data,
- 19 4. set up model (α , β) with the sensor data,
- 20 5. find new C, M, Y from equations,
- 21 6. iterate to reach desired accuracy, and
- 22 7. find \underline{t}_C , \underline{t}_M , \underline{t}_Y from data, for each C, M, Y.

23
24
25 (i) Fine tuning — The search can be further refined
26 if conducted in several printing passes, if there is a
27 need for finer accuracy. This iteration can be performed
28 in at least these ways:

29 The model pattern can be printed once again, but this
30 time all ramps are printed with the correction found in
31 the first effort — so that cK grays are closer to neutral
32 at the outset. The process then continues as before, and

1 the new color-correction values are linked with those
2 found in the first attempt.

3 Alternatively the complete-sampling and model-based
4 searches can be combined. Preferably the search is begun
5 with the modeling, to obtain gray-balancing functions as
6 above. Then taking the solutions as centerpoints, a com-
7 plete-sampling search is performed with very small incre-
8 ments, such as for example one percent.

9
10 (j) Contracted gamut — Modeling as described above
11 measures primaries and secondaries, i. e. fully saturated
12 colorants. This approach has the benefits of simplicity
13 and considering the full gamut.

14 The sampled space can be contracted transversely,
15 however, to probe at much finer resolution the region
16 nearest the gray axis. One way to implement this strategy
17 is to perform a simple change of base — in other words,
18 to define $C' = \underline{b}_C C$ (Fig. 9), $M' = \underline{b}_M M$, $Y' = \underline{b}_Y Y$, $R' = \underline{b}_R R$,
19 $G' = \underline{b}_G G$, $B' = \underline{b}_B B$.

20 The illustration is a diagram of CMY space. The sol-
21 id colored lines C, M, Y are the conventional orthogonal
22 axes, and the dashed colored lines C', M' and Y' are modi-
23 fied axes which have been, so to speak, "shrunk" or con-
24 tracted — so that they are closer to the gray axis G,
25 which appears as a solid gray line.

26 The parameter represented is how the axes are shrunk,
27 in terms of the angle of deviation. The angle of contrac-
28 tion is an angle in the plane that contains the primary
29 axis (e. g. C) under consideration and the gray axis G.

30 Orthogonal axes would be shrunk zero degrees, while
31 fully shrunk axes would be forty-five degrees. All values
32 intermediate between those are possible.

1 The change of base should be understood as very general;
2 hence the quantities \underline{b} are preferably vectors, or in the
3 alternative the change of base may be parametrized with \underline{b}
4 in order to contract more less (in which case \underline{b} may be
5 treated as scalar).

6 The several scaling vectors \underline{b} may be equal if pre-
7 ferred. On the other hand, if desired the new axes C' , M'
8 and Y' (Fig. 9) can be parametrized to shrink more or less
9 depending on the kind of medium etc. for which the cali-
10 bration is to apply.

11 For $|\underline{b}| > 1$ the effect is to consider washes, i. e.
12 less-saturated mixtures, of the primaries and secondaries.
13 Secondaries furthermore are now the composition of the
14 newly defined primaries, e. g. $B' = C' + M'$.

15 The modeling equations described above are now ap-
16 plied in exactly the same way as with the conventionally
17 defined base. Once the solution is found, in terms of
18 $C'M'Y'$, the inverse base change is applied to express the
19 results in terms of conventional CMY.

22 4. MECHANICAL AND PROGRAM/METHOD FEATURES

23
24 The invention is amenable to implementation in a
25 great variety of products. It can be embodied in a prin-
26 ter/plotter that includes a main case 1 (Fig. 10) with a
27 window 2, and a left-hand pod 3 which encloses one end of
28 the chassis. Within that enclosure are carriage-support
29 and -drive mechanics and one end of the printing-medium
30 advance mechanism, as well as a pen-refill station with
31 supplemental ink cartridges.

32 The printer/plotter also includes a printing-medium
33 roll cover 4, and a receiving bin 5 for lengths or sheets
34 of printing medium on which images have been formed, and

1 which have been ejected from the machine. A bottom brace
2 and storage shelf 6 spans the legs which support the two
3 ends of the case 1.

4 Just above the print-medium cover 4 is an entry slot
5 7 for receipt of continuous lengths of printing medium 4.
6 Also included are a lever 8 for control of the gripping of
7 the print medium by the machine.

8 A front-panel display 211 and controls 212 are moun-
9 ted in the skin of the right-hand pod 213. That pod en-
10 closes the right end of the carriage mechanics and of the
11 medium advance mechanism, and also a printhead cleaning
12 station. Near the bottom of the right-hand pod for readi-
13 est access is a standby switch 214.

14 Within the case 1 and pods 3, 213 a cylindrical plat-
15 en 241 (Fig. 11) — driven by a motor 242, worm and worm
16 gear (not shown) under control of signals from a digital
17 electronic processor 71 — rotates to drive sheets or
18 lengths of printing medium 4A in a medium-advance direc-
19 tion. Print medium 4A is thereby drawn out of the print-
20 medium roll cover 4.

21 Meanwhile a pen-holding carriage assembly 220 (Figs.
22 11 and 12) carries several pens 223-226 (Fig. 11) back and
23 forth across the printing medium, along a scanning track
24 — perpendicular to the medium-advance direction — while
25 the pens eject ink. As mentioned earlier, this is one but
26 not the only form of incremental-printing apparatus, an
27 alternative being use of a page-wide pen array with rela-
28 tive motion in relation to the full length of the printing
29 medium. (As will be understood, the term "scan" is also
30 used in describing motion of a measuring sensor over the
31 printing medium, most usually along the medium-advance
32 direction.)

33 For simplicity's sake, only four pens are illustra-
34 ted; however, as is well known a printer may have six pens

1 or more, to hold different colors — or different dilu-
2 tions of the same colors — as in the more-typical four
3 pens. The medium 4A thus receives inkdrops for formation
4 of a desired image, and is ejected into the print-medium
5 bin 5. A colorimetric image sensor 251, quite small,
6 rides on the carriage with the pens.

7
8 A very finely graduated encoder strip 233, 236 (Fig.
9 12) is extended taut along the scanning path of the car-
10 riage assembly 220 and read by another small automatic
11 optoelectronic sensor 237 to provide position and speed
12 information 237B for the microprocessor. One advantageous
13 location for the encoder strip is shown in several of the
14 earlier cross-referenced patent documents at 236, immedi-
15 ately behind the pens.

16 A currently preferred position for the encoder strip
17 233 (Fig. 11), however, is near the rear of the pen-car-
18 riage tray — remote from the space into which a user's
19 hands are inserted for servicing of the pen refill car-
20 tridges. For either position, the encoder-strip sensor
21 237 is disposed with its optical beam passing through
22 orifices or transparent portions of a scale formed in the
23 strip.

24 The pen-carriage assembly 220, 220' (Figs. 11 and 12)
25 is driven in reciprocation by a motor 231 — along dual
26 support and guide rails 232, 234 — through the intermedi-
27 ary of a drive belt 235. The motor 231 is under the con-
28 trol of signals from digital processors 71.

29 Naturally the pen-carriage assembly includes a for-
30 ward bay structure 222 for the pens — preferably at least
31 four pens 223-226 holding ink of four different colors
32 respectively. Most typically the inks are yellow in the
33 leftmost pen 223, then cyan 224, magenta 225 and black
34 226. As a practical matter, chromatic-color and black

1 pens may be in a single printer, either in a common car-
2 riage or plural carriages.

3 Also included in the pen-carriage assembly 220, 220'
4 is a rear tray 221 carrying various electronics. Figs. 10
5 and 11 most specifically represent a system such as the
6 Hewlett Packard printer/plotter model "DesignJet 1000",
7 which product does not include the present invention.
8 These drawings, however, also illustrate certain embodi-
9 ments of the invention, and — with certain detailed dif-
10 ferences mentioned below — a printer/plotter that in-
11 cludes preferred embodiments of the invention.

12
13 Before further discussion of details in the block
14 diagrammatic showing of Fig. 12, a general orientation to
15 that drawing may be helpful. Most portions 70, 73-78, 66
16 across the lower half of the diagram, including most 4A-
17 251 of the printing stage at far right, are generally con-
18 ventional and represent the context of the invention in an
19 inkjet printer/plotter.

20 The top portion 62-65, 80-85 of the drawing and
21 certain parts 251', 251" of the printing stage represent
22 the present invention. Given the statements of function
23 presented in this document, an experienced programmer of
24 ordinary skill in this field can prepare suitable programs
25 for operation of all the circuits.

26
27 The pen-carriage assembly is represented separately
28 at 220 when traveling to the left 216 while discharging
29 ink 218, and at 220' when traveling to the right 217 while
30 discharging ink 219. It will be understood that both 220
31 and 220' represent the same pen carriage.

32 The previously mentioned digital processor 71 pro-
33 vides control signals 220B to fire the pens with correct
34 timing, coordinated with platen drive control signals 242A

1 to the platen motor 242, and carriage drive control sig-
2 nals 231A to the carriage drive motor 231. The processor
3 71 develops these carriage drive signals 231A based partly
4 upon information about the carriage speed and position
5 derived from the encoder signals 237B provided by the
6 encoder 237.

7 (In the block diagram almost all illustrated signals
8 are flowing from top toward bottom and left toward right.
9 The exceptions are the information 237B fed back from the
10 codestrip sensor 237, the image-reflectance measurement
11 profile data 65 fed back from the colorimetric sensor 251,
12 and the scaling information 172 — all as indicated by the
13 associated leftward arrows.)

14 The codestrip 233, 236 thus enables formation of col-
15 or inkdrops at ultrahigh precision during scanning. This
16 precision is maintained in motion of the carriage assembly
17 220 in each direction — i. e., either left to right (for-
18 ward 220') or right to left (back 220).

19 New image data 70 are received 191 into an image-
20 processing stage 73, which may conventionally include a
21 contrast and color adjustment or correction module 76 and
22 rendition and scaling modules 74, 77, 77'. Most commonly,
23 scaling (if any) is performed in conjunction with rendi-
24 tion 75.

25 Information 193 passing from the image-processing
26 module 73 next enters a printmasking module 76. This gen-
27 erally includes a stage 77 for specific pass and nozzle
28 assignments.

29 Integrated circuits 71 may be distributive — being
30 partly in the printer, partly in an associated computer,
31 and partly in a separately packaged raster image proces-
32 sor. Alternatively the circuits may be primarily or whol-
33 ly in just one or two of such devices.

1 These circuits also may comprise a general-purpose
2 processor (e. g. the central processor of a general-pur-
3 pose computer) operating software such as may be held for
4 instance in a computer hard drive, or operating firmware
5 (e. g. held in a ROM 75 and for distribution 66 to other
6 components), or both; and may comprise application-spe-
7 cific integrated circuitry. Combinations of these may be
8 used instead.

9
10 As set forth above, images to be printed and scanned
11 to establish the modifications prescribed by the present
12 invention may be representative area-fill images of dif-
13 ferent colors, for reading by the optical sensor 251 to
14 generate calibration data. For generation of such test
15 images, the apparatus of the invention includes — in the
16 integrated-circuit section 71 (Fig. 12) — printing means
17 62 that generate control signals 80 for operation of the
18 final output stage 78. These signals drive the printing
19 stage seen at right.

20 In addition to the simple formatting instructions
21 necessary merely to define a geometrical pattern of test
22 patches 101, 111, 121-25, 131-35 (Fig. 1) — or alterna-
23 tively 171-74, 176-79 (Fig. 4) — the control signals 80
24 include a series of different colorimetric parameters for
25 test, as appropriate for establishing the multiple colors
26 of the patches respectively.

27 Such a series of parameters typically defines the
28 colorant deposition corresponding to the nominal ramp
29 colors, and in the case of the sampling method of Fig. 1
30 also includes a sequence of subtly differing color com-
31 mands defining the variations about each nominal color.
32 Each value is duly implemented by the final output stage
33 78 and its output signals 220B, 231A, 242A. These signals
34 are further implemented, in printing of the test images,

1 by the movements of the advance motor 242, drive 241 and
2 medium 4A.

3
4 A small automatic optoelectronic sensor 251 rides
5 with the pens on the carriage and is directed downward to
6 obtain data about color. More specifically, the sensor
7 measures color in the test patches, for purposes of the
8 adjustments set forth earlier in this document.

9 Ramp-measurement interpreting means 82 receive meas-
10 urement data 65 returned from the sensor 251. In the case
11 of the optimization embodiments, these interpreting means
12 82 include means for correlating these colorimetric data
13 65 with the phase of the waveband-selection signals 87 as
14 well as the colorimetric components of the previously
15 discussed output-stage control signals 80.

16 Based upon the colorimetric data 65 and correlations,
17 the ramp-measurement interpreting means 82 generate sig-
18 nals 83 for controlling the compensation means 84 — which
19 in turn produce signals 86 that adjust the otherwise gen-
20 erally conventional color-correction module 74. Through
21 refined cooperation of these several modules, the compen-
22 sation means 84 are able to minimize chroma in nominally
23 neutral image features — and also, as explained earlier,
24 to trim up the reproduction of color throughout the gamut
25 of the printing device.

26 More specifically, the compensation means 84 include
27 a calculation stage 85 that reduces chroma to roughly 2.5
28 ΔE or less. The notation ΔE represents color difference
29 in three-dimensional color space, particularly the percep-
30 tual CIELA*B* space.

31 As set forth in other patent documents, the same or
32 related data 65 can be used for control of other parame-
33 ters. These may include printmode; print-medium advance

1 speed and stroke; scan velocity; inkdrop energies, sizes
2 and velocities; depletion, propletion and discretionary-
3 dotting ratios; balance point between randomization vs.
4 granularity; and also nozzle weighting distributions.
5

6 The sensor 251 signals are coordinated (not shown)
7 with movements of the carriage and advance mechanism
8 during sensing. These signals are also coordinated with
9 operation of ramp-measurement controlling means 81 that
10 generate — among other control information — signals 87
11 for controlling the lamps 251' (Fig. 12) or wavelength-
12 differentiation unit 88 (Fig. 13).

13 In particular the lamps 251' advantageously take the
14 form of red, green and blue light-emitting diodes (LEDs)
15 R, G, B respectively. These diodes are energized by their
16 control signals 87 to produce specifically timed light
17 pulses 251" for illuminating the test pattern (Fig. 1 or
18 4) on the printing medium 4A — and thereby reflecting
19 light in specified wavebands into the sensor 251.

20 This enables discrimination of the reflected colors
21 as discussed earlier. In practice the lamps 251' are typ-
22 ically mounted within the housing of the sensor 251, and
23 thus are carried transversely across the printing medium
24 4A by the carriage 220 — as motivated 235 by the motor
25 231 and its control signals 231A. Propagation of the
26 light pulses 251" to the printing medium accordingly is
27 almost completely within the protected environment of the
28 sensor housing.

29
30 In an alternative illumination and sensing arrange-
31 ment, the light source is instead a broadband single
32 source 251'BB (Fig. 13), which emits broadband light
33 251"BB toward the test pattern on the medium 4A. In the
34 illustrated arrangement this light is allowed to illumi-

1 nate the test pattern, and the reflected light passes to a
2 wavelength differentiator 88.

3 The latter may be a controlled filter set (e. g. with
4 a rotating chopper), or a controlled birefringent disper-
5 sive device, or a controlled diffractive unit, or any
6 other module that spatially, temporally and/or absorp-
7 tively, or otherwise separates illumination from the spec-
8 tral bands of interest, within the broadband illumination
9 251"BB. Selected light 251"S passes to the sensor 251.

10 To establish which waveband is being received by the
11 sensor 251, or by particular elements within the sensor
12 251, the differentiator 88 is controlled by the signals 87
13 from the ramp-measurement controlling means 81. The sen-
14 sor signals 65 proceed as before to the interpreting means
15 82. In another alternative configuration the differentia-
16 tor 88 is located at a suitable point 89 in the illumina-
17 tion path.

18
19 Any of these versions of the illumination and sensing
20 subsystem thereby readily performs optical measurements
21 65, 82 (Fig. 12) of the printed test images. Suitable
22 algorithmic control is well within the skill of the art,
23 guided by the discussions here.

24
25 Method aspects of the invention may be conceptualized
26 as preferably including five distinct major steps 301,
27 302, 311, 321 and 331 (Fig. 14). All these operate auto-
28 matically, and as will be understood such operation may
29 begin with reading instructions 66 out of a nonvolatile
30 memory 72 (Fig. 12) for control of the several integrated-
31 circuit modules. To the extent that some functions may be
32 effected in an ASIC, however, no such reading step is
33 required as such; simply powering up the circuit initiates

1 operation of whatever functions the unit has been con-
2 structed to perform.

3 The first major function 301 includes using the
4 printing device to print a gray ramp with a single black
5 ink. In the secondary-calibrating variant or aspect of
6 the invention, actual red, green or blue ink may be used
7 instead.

8 The second major function 302 includes using the same
9 device to print a nominally gray ramp with composite-black
10 ink — or, for a secondary-calibrating facet or variant,
11 with two-primary nominal approximations to the desired
12 secondaries. This major step 302 is then followed by a
13 further major step 311 of automatically measuring and com-
14 paring the two ramps.

15 Next is a fourth major step 321 of employing the
16 measured black ramp as a standard to correct the measured
17 composite-black ramp — and this preferably includes a
18 chroma-correction operation 322. A fifth such step 331
19 includes using the compared ramps to also correct other
20 colors.

21
22 The two main methods of practicing the present inven-
23 tion are sampling 303-307, 322-325 and modeling 312-316,
24 326, 327. These alternatives are seen in the illustration
25 as two coordinated subchannels — to the left and right
26 respectively.

27 In particular, if sampling is favored then the print-
28 ing step 302 involves not only printing of a unitary com-
29 posite-black ramp as in the modeling case, but also the
30 substep 303 of printing plural nonblack combinations for
31 each gray tone to be calibrated.

32 Preferably this plural-combination printing substep
33 303 includes enough surrounding values to bracket 304 each
34 nominal value — and this in turn preferably includes op-

timizing 305 the bracketing, which optimizing itself preferably includes printing combinations that surround 306 the nominal value in color space.

When this approach is employed, then after the major measuring-and-comparing step 311, the employing step 321 is coordinated 307 with the printing substeps 303-306 by the particular form 323 of the chroma-correction substep 322. More specifically, either the measured nonblack combinations are searched 324 to find one of those combinations for use, or the system interpolates 325 among measured combinations — typically those which most closely surround the target true gray.

If instead modeling is employed, then the plural non-black-combination printing 303 is omitted — but when it is time for measurement and comparison 311, a new step of inserting 312 the measured values into equations is performed. It is this step 312, rather than the "particular form" 323 mentioned in the preceding paragraph, which is then linked 316 to a specialized substep 326 in the employing step 321 — namely, the substep of solving the equations to get the correction values for later use.

In the modeling case, the value-insertion substep 312 preferably includes using 313 expressions of the form presented in equation [1], [1'] earlier — and these expressions in turn preferably take 314, 315 the special forms that are described in the text immediately following equation [1']. As also noted earlier, the solution 326 is advantageously performed by iteration 327 of the equations.

As mentioned earlier, however, the sampling and modeling regimens may be hybridized in various ways. One particularly effective strategy for doing so is first to go through the Fig. 14 method using the modeling options

WHAT IS CLAIMED IS:

- 1 1. A method for color-calibrating a printing device;
2 said method comprising the steps of:
3 using the printing device to print a gray ramp with
4 black ink;
5 using the same said printing device to print a nomi-
6 nally gray ramp with composite-black ink;
7 measuring and comparing the printed gray ramps; and
8 employing the measured black-ink ramp as a standard
9 to correct the measured composite-black ramp.

- 1 2. The method of claim 1, wherein:
2 all the steps are performed automatically.

- 1 3. The method of claim 1, wherein:
2 the employing step comprises treating the black-ink
3 ramp as a zero-chroma standard to correct chroma found in
4 the composite-black ramp.

- 1 4. The method of claim 1, further comprising the step
2 of:
3 using the compared black-ink and composite-black
4 ramps to also correct other printing with composite black.

1 5. The method of claim 4, further comprising the step
2 of:

3 using the compared black-ink and composite-black
4 ramps to also correct other colors to be printed by the
5 printer.

1 6. The method of claim 1, wherein:

2 the using step with composite-black ink comprises
3 printing, for a particular gray tonal level, plural combi-
4 nations of nonblack inks.

1 7. The method of claim 6, wherein:

2 the plural combinations of nonblack inks substantial-
3 ly bracket nominal values for the particular gray value.

1 8. The method of claim 7, wherein the employing step
2 comprises:

3 searching the printed and measured plural combina-
4 tions of nonblack inks to find a combination that is
5 nearest the corresponding particular gray value.

1 9. The method of claim 7, wherein the employing step
2 comprises:

3 searching the printed and measured plural combina-
4 tions of nonblack inks to find at least two combinations
5 that bracket a corresponding particular gray value; and
6 interpolating among the at least two combinations to
7 determine an optimal combination for matching the corre-
8 sponding particular gray value.

1 10. The method of claim 7, wherein said printing with
2 plural combinations of nonblack inks comprises:
3 optimized bracketing of the nominal values.

1 11. The method of claim 10, wherein:
2 said optimized bracketing comprises printing with
3 said plural combinations of nonblack inks that surround
4 the nominal value in a pattern, in color space, that is
5 substantially centered on the nominal value.

1 12. The method of claim 6, wherein the employing step
2 comprises:
3 searching the printed and measured plural combina-
4 tions of nonblack inks to find a combination that is
5 nearest a corresponding particular gray value.

1 13. The method of claim 1, wherein:
2 the measuring and comparing step comprises inserting
3 measured values of the printed gray ramps into equations
4 representing a colorimetric model of the printer; and
5 the employing step comprises solving the equations to
6 derive correction values for use in adjusting ink signals
7 in future printing.

1 14. The method of claim 13, wherein:
2 the colorimetric equations include plural expressions
3 having the form:

4
5
$$H(t,n,a) = D(t,n) \cdot E(t,n) \cdot \dots \cdot F(t,n),$$

6

7 wherein H is a hybrid color printed by use of at least two
8 constituent colors,

9 D is one of the constituent colors,

10 E is another of the constituent colors,

11 ". . ." represents possible additional constituent
12 colors of said at least two,

13 F is a correction factor,

14 t is a tonal level at which H, D, E and ". . ." are evaluated,
15

16 n is a sensor channel at which all the above are
17 evaluated, and

18 a is a scaling factor that relates overall range
19 of the hybrid color with overall range of the
20 constituent colors.

1 15. The method of claim 14, wherein:

2 in some of the expressions, $H = cK$, $D = S_1$ and $E =$
3 S_2 , where cK is composite black and S_1 and S_2 are secondar-
4 ies; and

5 in others of the expressions, $H = S$, $D = P_1$ and $E =$
6 P_2 , where S is a secondary and P_1 and P_2 are primaries.

1 16. The method of claim 15, wherein:

2 in said others of the expressions a = 1.

1 17. The method of claim 13, wherein:
2 the equations are solved by iteration.

1 18. A self-calibrating color printer comprising:
2 means for printing a nominally gray ramp using com-
3 posite black;
4 means for measuring the printed ramp in at least two
5 different spectral bands respectively; and
6 a programmed processor for modifying subsequent op-
7 eration of the printer to substantially compensate for any
8 nonzero chroma in said printed nominally gray ramp.

1 19. The printer of claim 18, wherein:
2 said measuring means comprise means for measuring the
3 printed ramp in at least three different spectral bands.

1 20. The printer of claim 18, wherein said measuring means
2 comprise:
3 at least two different lamps for illuminating the
4 printed ramp; and
5 at least one sensor for detecting lamp illumination
6 reflected from the printed ramp.

1 21. The printer of claim 20, wherein:
2 the at least two different lamps are light-emitting
3 diodes, emitting different colors respectively.

1 22. The printer of claim 18, wherein said measuring means
2 comprise:

3 means for illuminating the printed ramp in at least
4 two spectral bands; and

5 at least one sensor for detecting illumination re-
6 flected from the printed ramp in the at least two spectral
7 bands separately.

1 23. The printer of claim 22, wherein:

2 the illuminating means comprise a lamp emitting in
3 the at least two spectral bands; and

4 the sensor comprises spatially, temporally or absorp-
5 tively selective means for separating illumination from
6 the at least two spectral bands.

1 24. The printer of claim 18, wherein:

2 the programmed processor comprises compensation means
3 for adjusting subsequent operation to substantially mini-
4 mize chroma in printing of nominal gray.

1 25. The printer of claim 24, wherein:

2 the compensation means comprise means for reducing
3 chroma, in printing of nominal gray, to ΔE of approximate-
4 ly 2.5 or less; and

5 the notation ΔE represents the color distance in the
6 CIEL*a*b* space.

1 26. A method for automatically color-calibrating a prin-
2 ter; said method comprising the steps of:
3 using the printer to print a ramp in a particular
4 color with actual ink of that color;
5 using the same said printer to print a ramp nominally
6 in said particular color but with inks of other colors;
7 measuring and comparing the printed ramps; and
8 using the measured actual-ink ramp as a standard to
9 calibrate and correct the measured other-colors-ink ramp
10 and also to correct other printing with said other colors.

1 27. The printer of claim 26, wherein:
2 said actual ink is selected from the group consisting
3 of:
4 red ink,
5 green ink, and
6 blue ink;
7
8 and said inks of other colors are selected from the
9 group consisting of, respectively:
10
11 magenta ink and yellow ink,
12 yellow ink and cyan ink, and
13 cyan ink and magenta ink.

1 28. A method for automatically color-calibrating a prin-
2 ter; said method comprising the steps of:
3 modeling an actual color-reproduction system of the
4 printer in a color space that is transformed by contrac-
5 tion to bring machine-primary color axes closer to neutral
6 gray;
7 performing a color calibration in the contracted mod-
8 el of the printer color-reproduction system; and
9 applying a reverse transform to expand calibration
10 results to the actual color-reproduction system of the
11 printer.

1 PRINTING A TRUE-INK REFERENCE, AND REFINING GRAY ACCURACY,
2 FOR OPTIMUM COLOR CALIBRATION IN INCREMENTAL PRINTING

3
4
5 ABSTRACT OF THE DISCLOSURE
6

7 Ramps are printed with ink of a particular color, and
8 also nominally in that color but by inks of other colors.
9 A measured actual-ink ramp is a standard to fix the other-
10 colors ramp, and correct other printing in those colors.
11 In one aspect a particular color is gray, actual ink black
12 (K), and other-color inks magenta (M), yellow (Y) and cyan
13 (C). In another aspect, actual ink is red (R), green (G)
14 or blue (B); other colors M, Y and C in respective pairs.
15 For gray/black, the K ramp is a zero-chroma standard to
16 lower composite-black (cK) chroma below $\sim 2.5 \Delta E$. A sam-
17 pling aspect prints for each gray tone plural cK-ink com-
18 binations preferably bracketing nominal gray values; and
19 searches these combinations to get one nearest the partic-
20 ular gray — or most closely bracketing it, for interpola-
21 tion — for best match. Bracketing is best optimized, by
22 a color-space pattern centered on nominal. A modeling as-
23 pect inserts measured-ramp values into printer color-model
24 equations, and solves (best by iteration) for best match.
25 Equations are best of form $H = D \cdot E \cdot \dots \cdot F$; H a hybrid
26 of two or more colors D, E . . . ; F a correction factor.
27 In some expressions $H = cK$, $D = S_1$ and $E = S_2$ (S_1 and S_2
28 secondaries); in others $H = S$, $D = P_1$ and $E = P_2$ (P_1 and P_2
29 primaries). Another aspect models in a space transformed
30 by shrinking primary axes near neutral; after calibration
31 in shrunk space, an inverse transform reexpands results.

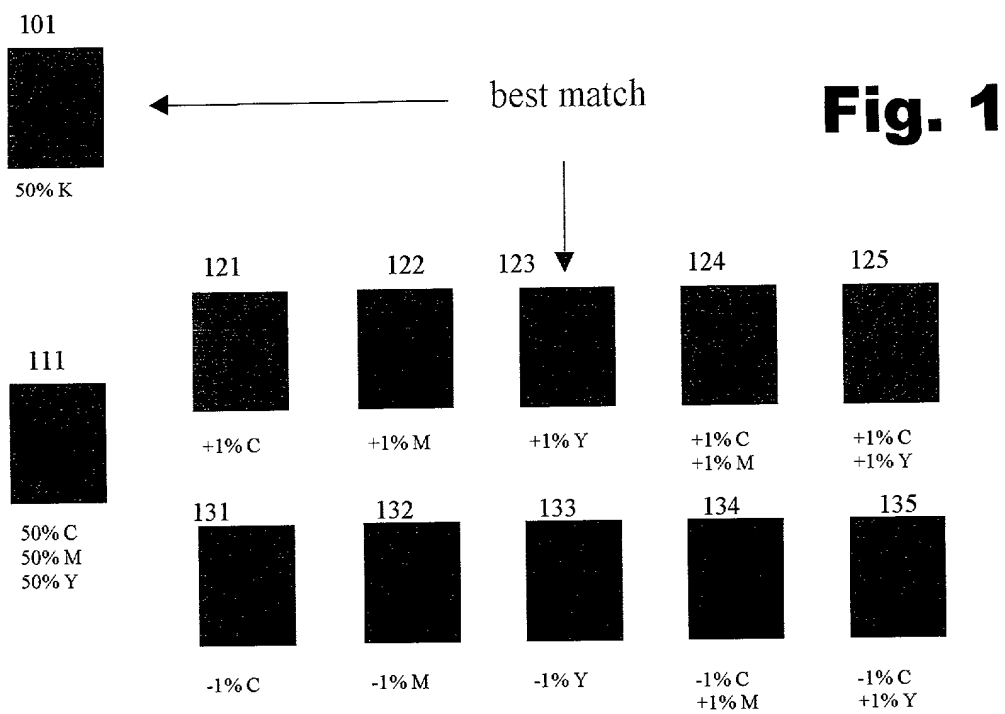


Fig. 2

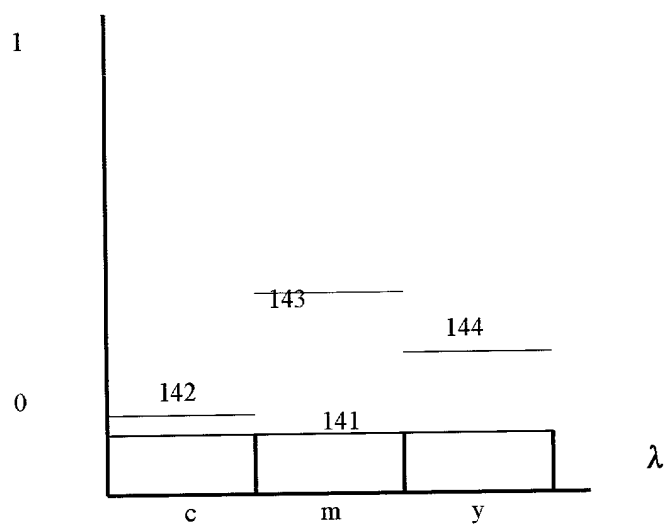


Fig. 3

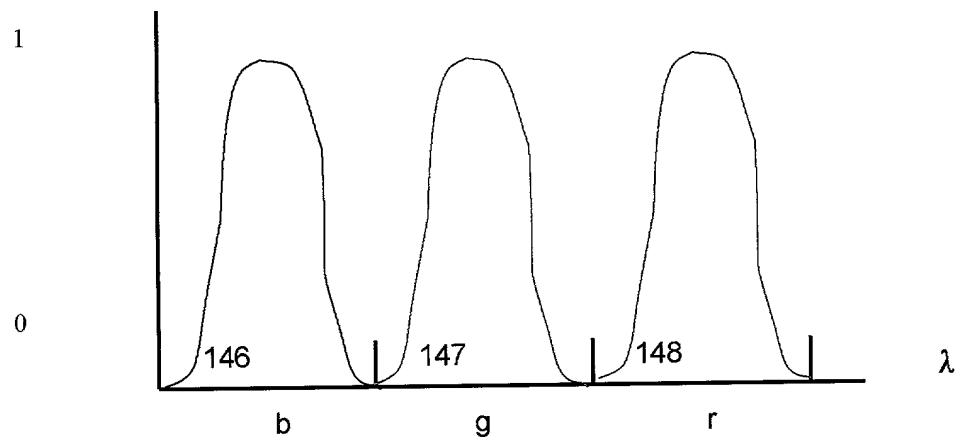


Fig. 4

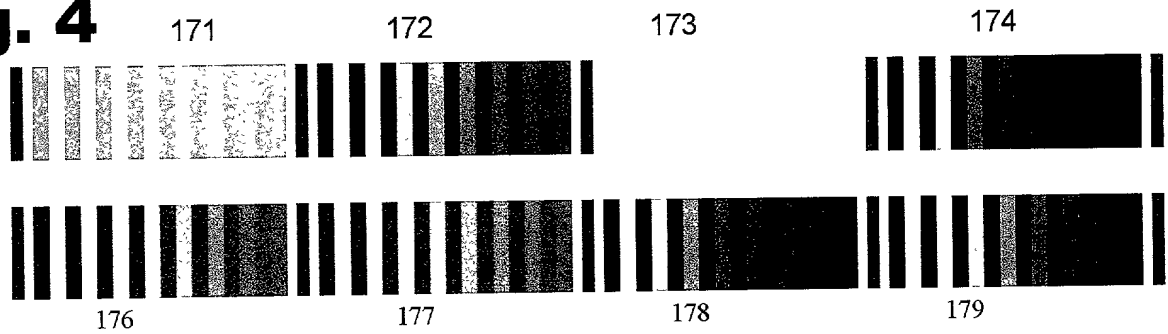


Fig. 5

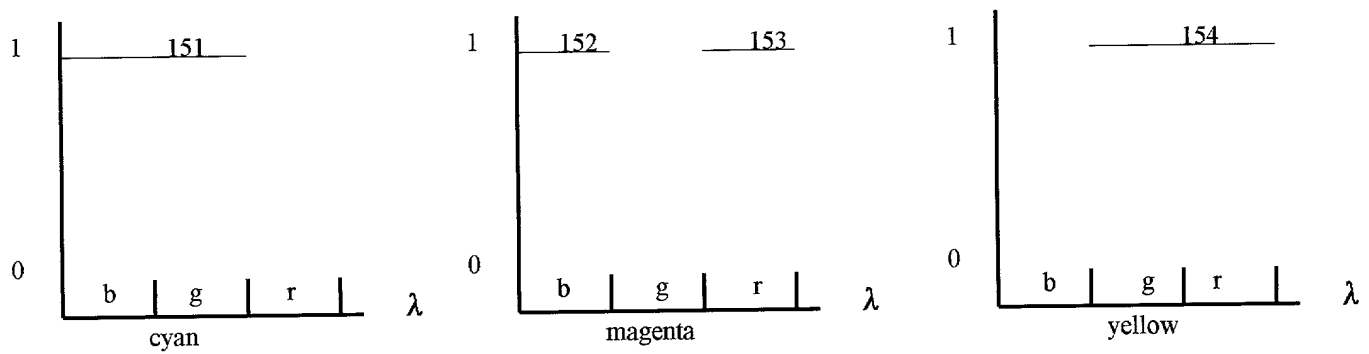


Fig. 6

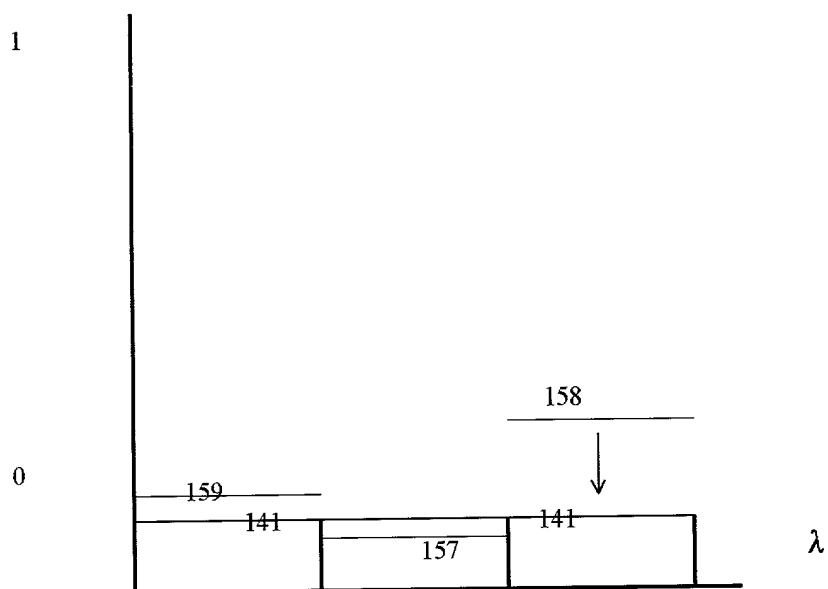


Fig. 7

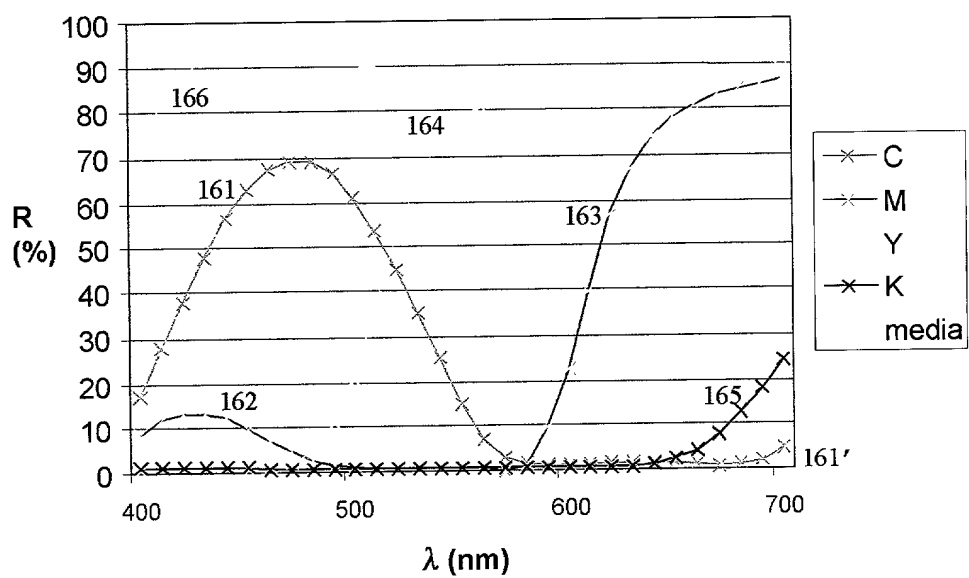


Fig. 8

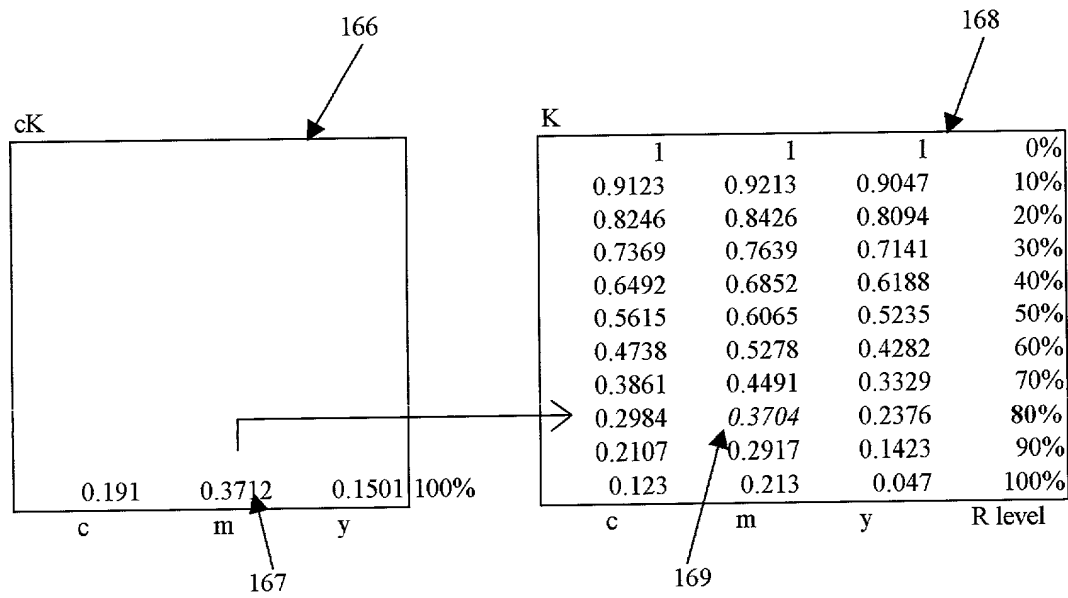
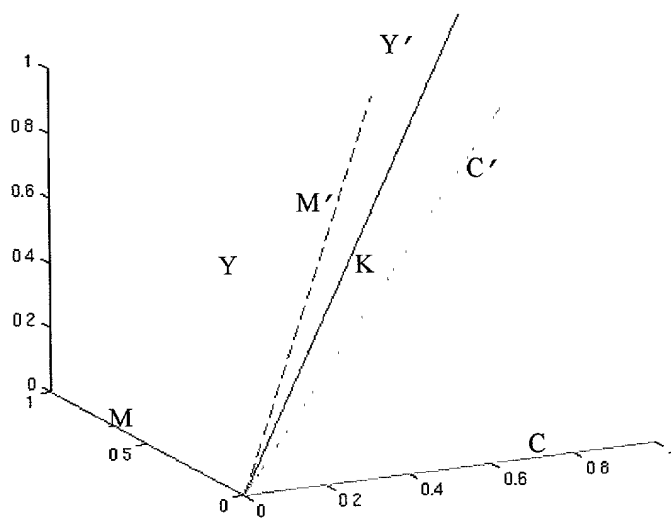


Fig. 9



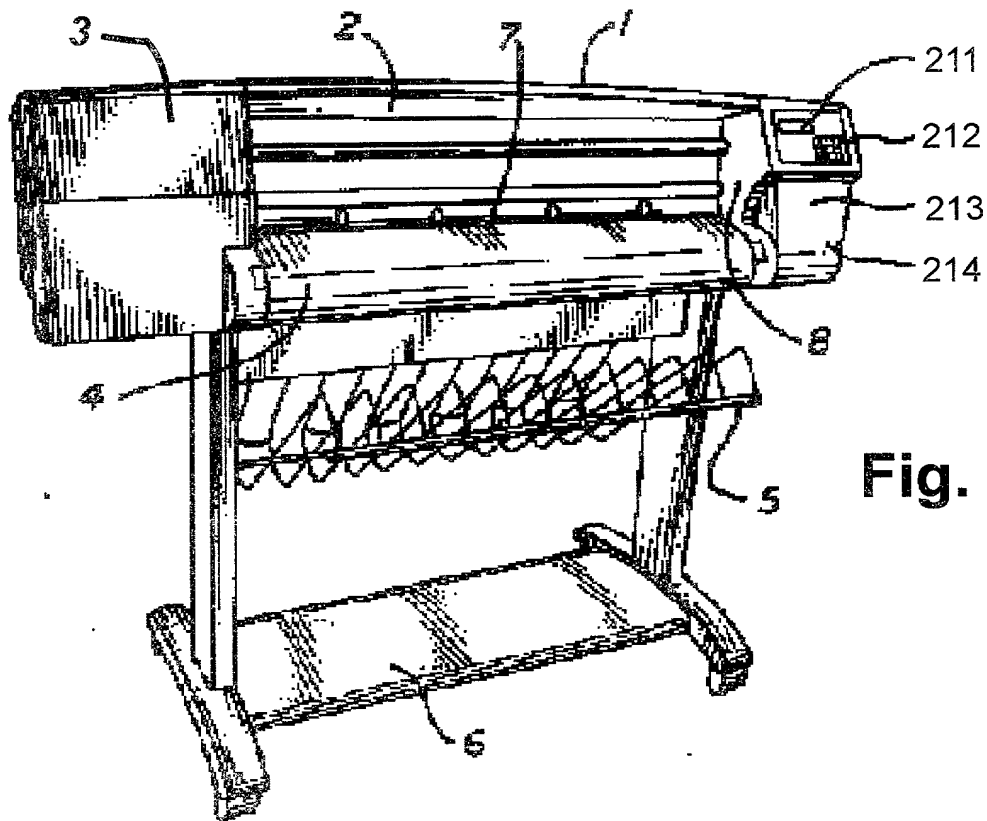


Fig. 10

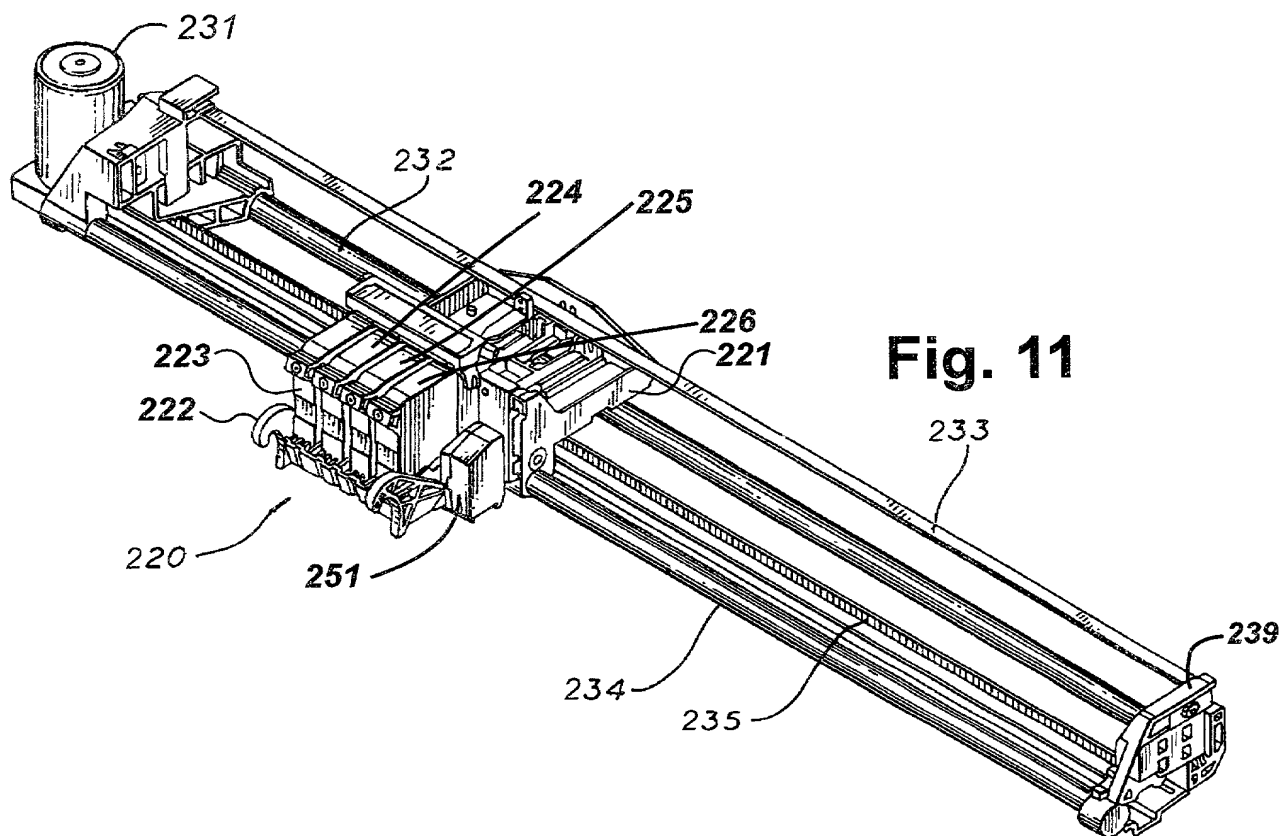


Fig. 11

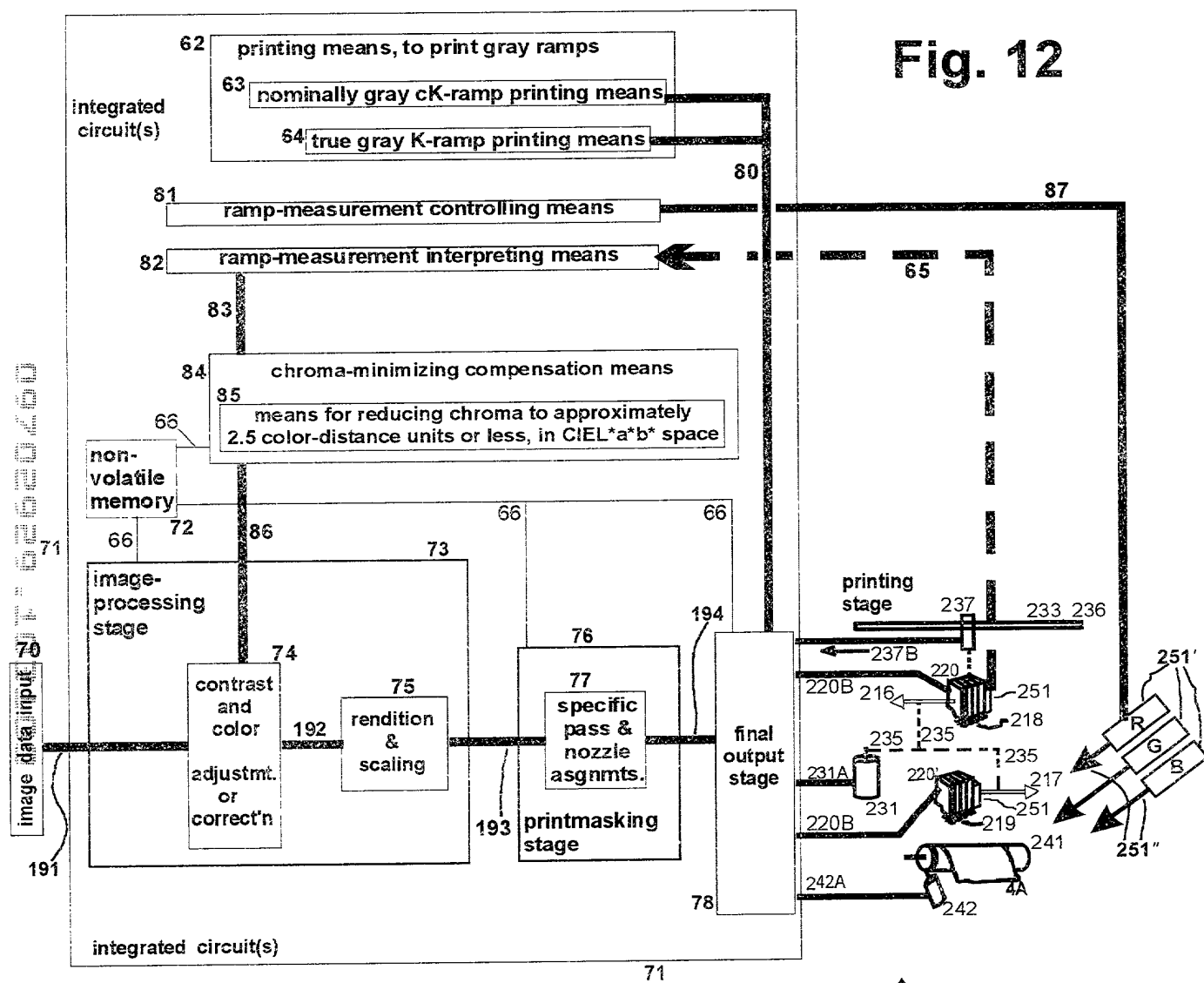


Fig. 14

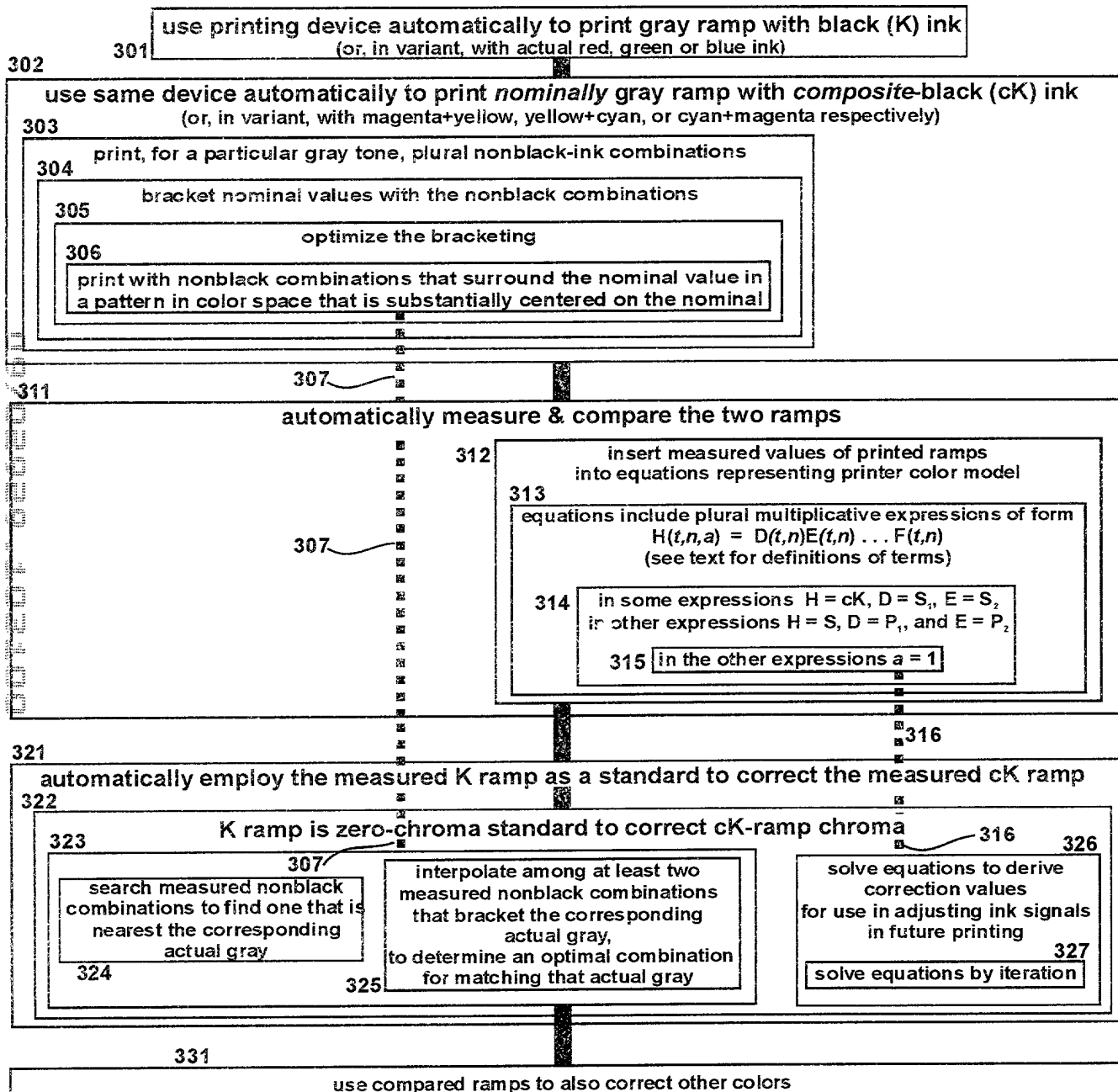


Fig. 15

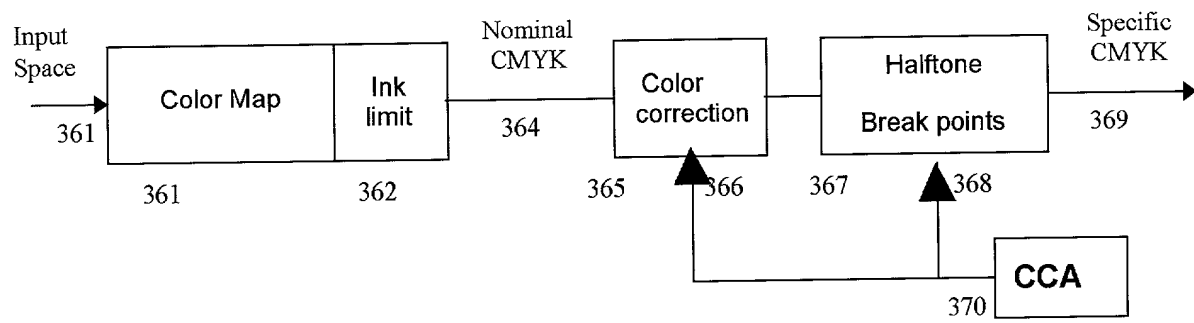
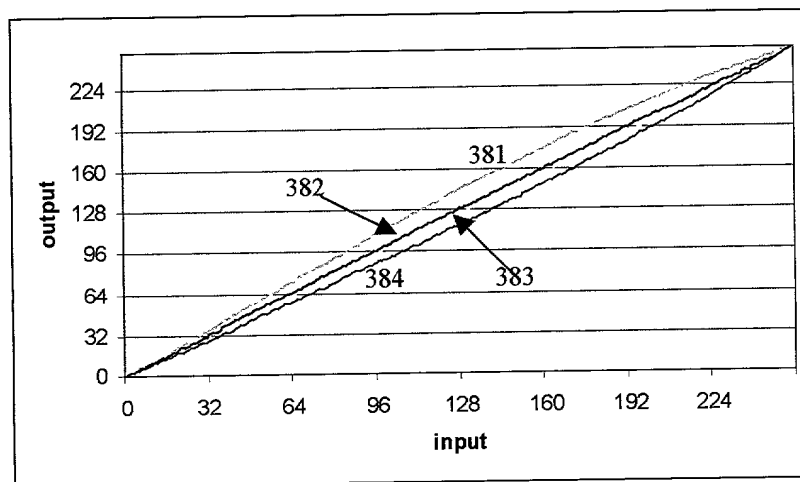


Fig. 16



**DECLARATION AND POWER OF ATTORNEY
FOR PATENT APPLICATION**ATTORNEY DOCKET NO. 60002642
(xHPZ-32)

As a below named inventor, I hereby declare that:

My residence/post office address and citizenship are as stated below next to my name;

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

**"PRINTING A TRUE-INK REFERENCE, AND REFINING GRAY ACCURACY,
FOR OPTIMUM COLOR CALIBRATION IN INCREMENTAL PRINTING"**

the specification of which

☒ is attached hereto. (Leave blank in response to Notice of Missing Parts)☐ was filed on _____ as Application Serial No. 09/ , _____☐ was amended by the preliminary amendment filed with the original application papers.

I hereby state that I have reviewed and understood the contents of the above-identified specification, including the claims, as amended by any amendment(s) referred to above and that I have disclosed the best mode for carrying out the invention as of the effective filing date of this application. I acknowledge the duty to disclose all information which is material to patentability as defined in 37 CFR 1.56. If this is a continuation-in-part application, I acknowledge the duty to disclose all information known to me to be material to patentability as defined in 37 CFR 1.56 which became available between the filing date of the prior (priority) application and the National or PCT international filing date of this continuation-in-part application.

☐ In compliance with this duty there is attached an information disclosure statement 37 CFR 1.97.**Foreign Application(s) and/or Claim of Foreign Priority**

I hereby claim foreign priority benefits under Title 35, United States Code Section 119 of any foreign application(s) for patent or inventor(s) certificate listed below and have also identified below any foreign application for patent or inventor(s) certificate having a filing date before that of the application on which priority is claimed:

COUNTRY	APPLICATION NUMBER	DATE FILED	PRIORITY CLAIMED UNDER 35 U.S.C. 119
- none -	-	-	YES: <input type="checkbox"/> NO: <input type="checkbox"/>
			YES: <input type="checkbox"/> NO: <input type="checkbox"/>
			YES: <input type="checkbox"/> NO: <input type="checkbox"/>

U. S. Priority Claim

I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code Section 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, Section 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

APPLICATION SERIAL NUMBER	FILING DATE	STATUS (patented/pending/abandoned)
- none -	-	-

POWER OF ATTORNEY:

As a named inventor, I hereby appoint the attorney(s) and/or agent(s) listed below to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full Name of Inventor: Pau SolerCitizenship: SpainResidence/Post Office Address: Avenida Graells 50108190 Sant Cugat del Valles (Barcelona) SPAIN

Inventor's Signature _____

October , 2000
Date